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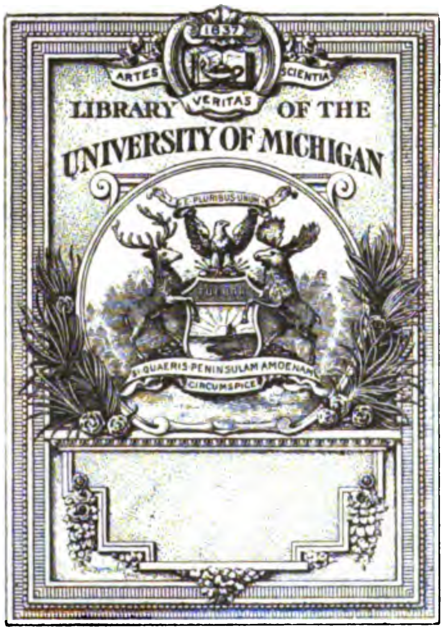

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BUREAU OF ANIMAL INDUSTRY—BULLETIN 421.
A. D. MELVIN, CHIEF OF BUREAU.

# THE NEED OF CONTROLLING AND STANDARDIZING THE MANUFACTURE OF VETERINARY TETANUS ANTITOXIN.

BY

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WASHINGTON:
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1909.

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# LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
*Washington, D. C., November 2, 1909.*

Sir: I have the honor to transmit herewith and to recommend for publication in the bulletin series of this Bureau a manuscript entitled "The Need of Controlling and Standardizing the Manufacture of Veterinary Tetanus Antitoxin," by Dr. John R. Mohler, chief of the Pathological Division of this Bureau, and Dr. Adolph Eichhorn, bacteriologist in that division.

The investigation reported in this paper was undertaken in accordance with the act of Congress making appropriations for the Department of Agriculture for the past fiscal year, which empowered the Secretary of Agriculture to purchase in the open market samples of tuberculin, serums, antitoxins, etc., designed for veterinary use, to test the same, and to publish the results of such tests. This act does not, however, confer any authority to supervise or control the manufacture of these products.

It has become known in the veterinary profession that tetanus antitoxin for veterinary use—unlike that for human use, which is manufactured under stringent government supervision—is urgently in need of standardization. Under existing conditions the veterinarian and the stock owner are at the mercy of the manufacturers of this antitoxin, some of whom make no statement as to the strength of their product, while in the great majority of the cases tested in the present investigation it was found that the standard was not reached and many of the samples were far below it.

It is very necessary that the veterinarian should have some reliable assurance of the strength of this most valuable therapeutic agent. There is, therefore, pressing need for legislation empowering the Secretary of Agriculture to supervise and control the manufacture of veterinary tetanus antitoxins and to prescribe and enforce a proper standard of potency. Such authority, of course, would be limited to products manufactured for interstate commerce or offered for importation.

Very respectfully,
A. D. Melvin,
*Chief of Bureau.*

Hon. James Wilson,
*Secretary of Agriculture.*

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# THE NEED OF CONTROLLING AND STANDARDIZING THE MANUFACTURE OF VETERINARY TETANUS ANTITOXIN.

## INTRODUCTION.

Of the various biological products prepared for the cure and prevention of infective diseases in animals tetanus antitoxin has been probably the most extensively used by the veterinary profession. The good effects which were expected from the administration of this antitoxin in the prophylactic and curative treatment of tetanus have not, however, been all that could be desired, and it is surprising to learn of the divergent results which are obtained from its use by various practitioners. It is therefore only natural that tetanus antitoxin has not gained the favor of the veterinarian and is not used to the extent merited by such a valuable product. It has been suggested that the lack of uniform results which has followed the administration of the antitoxin is primarily due to the variation in the strength of the product, and following numerous requests from different sources it was decided to undertake the standardization of veterinary tetanus antitoxins prepared by different manufacturers, and also to determine whether these products are subject to any variations in strength. This work seemed particularly desirable in view of the address of Anderson before the June meeting of the American Medical Association, in which he stated that his experiments showed veterinary tetanus antitoxin to contain as low as 17 to 25 antitoxin units per cubic centimeter, while similar examinations of antitoxin prepared for medical use contained from 150 units to 600 or even 700 units per cubic centimeter.

The investigation herein recorded was carried out in accordance with an act of Congress making appropriations for the Department of Agriculture for the year ending June 30, 1909, which provides as follows:

> That the Secretary of Agriculture is authorized to purchase in the open market samples of all tuberculin, serums, antitoxins, or analogous products, of foreign or domestic manufacture, which are sold in the United States for the detection, prevention, treatment, or cure of diseases of domestic animals, to test the same, and to publish the results of said tests in such a manner as he may deem best.

It should be noticed that while power has been granted to purchase, test, and publish upon these products, no authority has been given with reference to the supervision and control of their manufacture. This paper is presented with the object of furnishing some concrete examples of the variation observed in tetanus antitoxin at present on the market, and to show the necessity for Federal supervision of all vaccines, serums, antitoxins, viruses, and analogous products, including mallein, tuberculin, anthrax and blackleg vaccine, and hog-cholera serum.

## NATURE AND CAUSE OF TETANUS.

Tetanus is an extremely painful disease of all animals, including man, but it more particularly affects the horse, ass, and mule. It is caused by the *Bacillus tetani.* This organism differs from other disease-producing bacteria in the fact that it remains localized at the point of entrance to the body, which is usually through a wound. Here it multiplies and produces a powerful toxin which is absorbed into the circulation and, by acting on the nervous system, gives rise to the symptoms of the disease. From this it will be seen that tetanus is the type of the purely toxic disease and is not transmissible by contact unless the wound containing the germ is discharging pus or blood, as may be the case in tetanus following the operation of castration. Neither can the disease be transmitted from one animal to another by blood inoculation, because no bacilli are circulating in the blood. The bacillus is a spore former, and these spores are very resistant to antiseptics. It can live outside the animal body, and is quite prevalent in garden earth and in the neighborhood of manure piles. It is an anaerobic organism like the bacillus of blackleg, and consequently can multiply only in the absence of oxygen. Deep punctured wounds about the feet and legs are especially serious, as in wounds of this kind the bacilli are most likely to be implanted, and once they have gained access the absence of oxygen in these deep wounds makes the conditions favorable for their growth. The period of incubation varies from a few days to two weeks.

The symptoms come on gradually. There is stiffness of the gait and rigidity of the muscles, the appearance of the animal somewhat resembling a horse foundered in all four feet. The neck is rigid, the head extended, and the tail elevated and immovable. The characteristic symptom of tetanus is the protrusion of the nictitans membrane over the eye when the head is raised. This condition is due to a contraction of the muscles of the eyeball drawing it back into its socket and forcing out the nictitans membrane. There is no other disease in which this condition is present. The animal is extremely nervous, starts at the slightest sound, loses its appetite, and sweats freely. There is a spasmodic contraction of certain groups of muscles, especially those of the jaw, so that the animal is unable to open its mouth, from which the disease derives its popular name of lockjaw. The malady runs an irregular course and death may occur in a few days or the affection may be prolonged over two or three weeks. Spontaneous recovery is very doubtful, and the outlook is always grave. The mortality for some classes of animals has been given as almost 100 per cent, while about 75 per cent of the cases in horses terminate fatally. Unfortunately the disease is seldom suspected until a relatively large amount of toxin has formed and begun to manifest its action in the patient's body.

## HISTORICAL SUMMARY.

Prior to the discovery of the cause of tetanus there were various theories advanced regarding the character of the disease. One of the most widely accepted views was that tetanus, since it generally develops as a result of an injury, was occasioned by the tearing or contusion of some of the peripheral nerves and as a consequence the changes produced were conveyed to the spinal cord. On the other hand, in the cases where no injury was associated with the disease it was thought to be of idiopathic origin.

With the discovery of the tetanus bacillus by Nicolaier in 1884 and its successful cultivation by Kitasato in 1889, the true cause of the disease, which previously had been involved in mystery, was established. Kitasato in his investigations also found that the organism is not present in the blood of animals dying of the affection, and accordingly he concluded that the fatal results were produced by an intoxication and not by the infection. In his subsequent work with this disease he, together with Von Behring, successfully worked out and published an immunizing method in 1890.

It has already been stated that in tetanus, unlike most of the other infectious diseases, the organism itself does not exert the destructive influence, only the toxins of the organisms being responsible for the serious results of the disease. The tetanus bacilli therefore produce a specific substance which has the toxic effect. Kitasato came to this conclusion in the course of his experiment when he succeeded in producing typical cases of tetanus in mice, guinea pigs, rabbits, and other animals with the filtrate obtained by filtering tetanus cultures through porcelain filters. At the same time he found that it required only a remarkably small quantity of the toxin to produce tetanus with a fatal termination in these animals

In the above-mentioned epoch-making work of Von Behring and Kitasato they attributed the established immunity to the effect of the blood serum, which rendered harmless the toxic substances produced by the tetanus bacillus. From the following described experiments they obtained results demonstrating that the serum had an enormous power of destroying the poison:

Of a tetanus culture 10 days old which was freed from bacilli by filtration, 0.00005 c. c. was sufficient to kill a mouse in four to six days, and 0.0001 c. c. was sufficient to kill a mouse with certainty in two days. However, 5 c. c. of the serum from the tetanus-immune rabbits were mixed with 1 c. c. of this culture and the serum was allowed to act upon it for twenty-four hours. Four mice were each given 0.2 c. c. of the mixture, which contained 0.0033 c. c. of the culture, or more than 300 times the dose otherwise fatal for mice. All four of the mice remained well. The control mice, on the other hand, died in thirty-six hours after having received 0.0001 c. c. of the fluid. As a result of these and other experiments the authors drew the following conclusions:

1. The blood of tetanus-immune rabbits possesses the property of destroying the tetanus poison.
2. This property is destroyed by the extra vascular blood and the cell-free serum obtained from it.
3. This property is of such a stable nature that it is also effective in the bodies of other animals, so that we are in position to accomplish noteworthy therapeutic results by means of the transfer of blood serum.
4. The property of destroying the tetanus poison is absent in the blood of animals which have not been immunized against tetanus. If tetanus be given to susceptible animals the toxin may be demonstrated in the blood and other body fluids after the death of the animals.

Tizzoni and Cattain have also established that the blood of artificially immunized pigeons and dogs has a protective action on mice and rats against the tetanus toxin (1 to 2 drops of the dog serum made 0.5 c. c. of a toxic culture filtrate ineffective).

With these wonderful results as a foundation, the serum therapy of tetanus was established.

The practical application of this method was inaugurated after Schütz had found that horses and sheep can also be successfully immunized against tetanus and that they produce an active immunizing serum. Horses are now exclusively used for the production of tetanus antitoxin, as large quantities of blood may be drawn from an immunized horse, which constitutes a great advantage in the manufacturing of this product for the market.

The immunizing serum is prepared according to Von Behring's method in the following way: Of 200 c. c. of a virulent bouillon culture, of which 0.75 c. c. kills a rabbit in three to four days, 80 c. c. is mixed with sufficient trichlorid of iodin to make a 0.25 per cent solution; similarly, 60 c. c. is mixed with enough to make a 0.175 per cent solution, and 40 c. c. with sufficient to make a 0.125 per cent solution, while the remaining 20 c. c. of the culture is left without any addition. The horse is then injected every eight days, commencing with 10 to 20 c. c. of the greatest dilution and continuing successively with the weaker attenuations of the culture. Finally the pure culture is injected, commencing with 0.5 c. c. and doubling the dose every five days, until no reaction to the culture is manifested and the blood shows the highest number of immunity units obtainable from that individual animal.

### MODE OF ACTION OF TETANUS TOXIN.

The highly poisonous qualities of this toxin and the fact that the organism causing the disease acts only through the generated toxin induced a greater number of investigators to carry out various investigations in connection therewith. The tetanus bacillus, it will be remembered, does not enter the general organism, but remains at the point of entrance (wounds) and only exerts its destructive effect through the action of the toxins which it eliminates. From the place of infection the toxin is conveyed principally by the nerves to the central nervous system, and here is its point of attack. The central nervous system, and especially the spinal cord, is first affected by the toxin, and all functional manifestations of the intoxication, as well as the increased reflex irritability, such as the tonic spasms of the muscles, are the result of the poisoning of the nerve cells of the spinal cord. That the muscle itself is not directly influenced in its function by the tetanic poison is no longer doubted by pathologists.

The tetanus toxin is taken up by the peripheral nerve endings and is then conducted by the nerves to the medullary centers, where it combines with the motor nerve cells. The poisoning of these cells then produces the tonic muscular spasms as well as the reflex irritability (Meyer and Ransom, Bruschettini, Stinzing, Von Behring, and others).

The mode of action of the tetanus toxin is explained by Ehrlich's side-chain theory in the following way: Every toxin molecule consists of a nonpoisonous (haptophore) and a poisonous (toxaphore) atom group. On the other hand, the protoplasm of the motor nerve cells consists of a vital nucleus and of numerous side chains (receptors), of which some possess a special affinity toward the haptophore atom groups of the toxin molecules. If molecules of the tetanus poison enter the nerve cells, they become anchored to the corresponding receptors of the cell protoplasm by the haptophore atom group, and their toxophore group exerts a harmful effect on the vital nucleus of the cell. There follows either a total destruction of the cell protoplasm as a result of this combination or a stimulation of the cell protoplasm to defensive action which is manifested by the continual production and elimination of the receptors into the blood.

The presence of these free receptors in the blood of immunized animals explains the antitoxic immunity, since these receptors are enabled to combine with the haptophore atom of the toxin molecule before it has had an opportunity to attack the cell protoplasm.

The tetanus toxin, according to Ehrlich, contains at least two poisons, the tetano-lysin and the tetano-spasmin. He showed that on the relative proportions of these poisons depends whether the toxin has stronger tetanic properties and a weaker hemolytic action, or vice versa.

### TOXICITY OF TETANUS TOXIN.

Testing the tetanus toxin for its virulence, Kitasato found that 0.0002 c. c. of the filtrate of a tetanus culture proved fatal to a mouse, while 0.002 c. c. killed a guinea pig weighing 560 grams. A rabbit, on the other hand, required relatively double the quantity of the mouse and almost seven times as much as the guinea pig, since it required 0.04 c. c. of the filtrate to kill a rabbit weighing 1,490 grams. Accordingly, of these three species of experimental animals the guinea pigs are the most susceptible to tetanus toxin, mice coming next and rabbits last. Of all animals the horse is probably the most susceptible to this toxin.

The remarkable poisoning qualities of tetanus toxin can be seen from the findings of Briszer and Cohn; 0.00000005 gram of their strongest tetanus toxin killed mice weighing 15 grams. Smaller doses, as 0.00000001 gram, caused tetanic symptoms in mice. The minimal lethal dose (MLD) of the standard tetanus toxin of the Hygienic Laboratory of the United States Public Health and Marine-Hospital Service is 0.000006 gram for a guinea pig weighing 350 grams.

### STABILITY OF TETANUS TOXIN.

Kitasato was the first to make extensive tests on the stability of the tetanus toxin, and while other investigators have since undertaken similar work with it the results they have obtained merely confirmed the findings of Kitasato.

In experimenting upon the effect of physical influences on the filtrate, Kitasato found that tetanus toxin is quite susceptible to heat. Subjected to 65° C. and above, it is totally destroyed in five minutes, while it resists 60° for fifteen minutes, but twenty minutes' exposure to this temperature destroys it. The drying of the filtrate does not necessarily destroy its virulence. However, a great deal depends upon the method of drying, as for instance, if dried in the incubator it is entirely destroyed, while if dried in the exsiccator over sulphuric acid or in the air at room temperature it retains its virulence. Exposure of the filtrate to diffused light showed a gradual diminishing effect upon its toxic action; however, it requires a long time before its virulence is entirely destroyed, as the filtrate which had been exposed for nine to ten weeks to the diffused light in the window still had toxic effects in large doses. On the other hand, the filtrate retains its virulence for a very long period if kept cold in a dark room, since it did not lose any of its virulence after three hundred days under such conditions. Exposure of the filtrate to direct sunlight proved that it is entirely destroyed only after fifteen to eighteen hours, while action of the filtrate. Dilutions of the filtrate with water or bouillon shorter exposure showed a corresponding diminution of the toxic does not influence the virulence of the tetanus poison.

Of the chemical influences on the filtrate Kitasato found that tetanus toxin is very susceptible to the action of acids (especially mineral acids) as well as alkalies.

Practically the same results were obtained by Rosenau and Anderson regarding the stability of the tetanus toxin, and as a result of their extensive investigation with the dried toxin they found that it not only retains its virulence when kept in a cold, dark place, but loses its toxicity quite slowly when exposed to light, heat, and other influences. One sealed tube sent from Washington to Manila by mail arrived there without appreciable loss of toxicity. The stability of the dried toxin is of great advantage in the work of standardization of the antitoxins, as it assures accurate work and also simplifies and expedites the tests.

## THE STANDARDIZATION OF TETANUS ANTITOXIN.

### EUROPEAN METHODS.

With the establishment of the principles of immunizing against tetanus by Von Behring and Kitasato, it became necessary to adopt a method by which the potency of the antitoxin could be accurately determined. In Germany the testing of the tetanus antitoxin is carried out in accordance with the Von Behring method, which provides that normal serum shall be a serum of which 0.1 c. c. renders ineffective 0.03 gram of normal toxin. This normal or test toxin is a dried toxin, 1 gram of which has a virulence capable of killing 10,000,000 mice each weighing 15 grams. The Italian method of standardizing tetanus antitoxin is based on the work of Tizzoni and Cattain. The toxin unit, according to this method, is the smallest amount of toxin which will kill a rabbit weighing 1 kilogram in from four to five days The Tizzoni antitoxin contains 80,000 immunity units in every cubic centimeter; in other words, this amount of antitoxin will neutralize 80,000 toxin units.

The French method of standardizing tetanus antitoxin is carried out by the subcutaneous inoculation of a series of guinea pigs with quantities of serum equal to $\frac{1}{500000}$, $\frac{1}{1000000}$, $\frac{1}{1500000}$, etc., of their weight. Twenty hours later these test animals are given a single fatal dose of toxin and the immunizing power of the serum is then considered to be $\frac{1}{500000}$ or $\frac{1}{1000000}$, etc., dependent upon whether the animal receiving this proportional weight of serum has survived the toxin which proved fatal to the control guinea pig.

### THE AMERICAN METHOD OF STANDARDIZATION.

The method of standardization which was carried out in connection with the testing of the veterinary antitoxins as reported in this paper followed the exact lines of the method known as the American method, which has been adopted officially under the biological product act of July 1, 1902.

This method, which is the result of several years' work on this subject in the Hygienic Laboratory, is a highly creditable achievement by Rosenau and Anderson,[a] as it not only simplifies the standardization of this valuable serum, but is also perfectly reliable in its accuracy. The method was also unanimously adopted by the Society of American Bacteriologists subsequent to the following report made by a special committee:

> That tetanus antitoxin be standardized by the tetanus toxin furnished by the Public Health and Marine-Hospital Service. The unit is ten times the least amount of serum necessary to save the life of a 350-gram guinea pig for ninety-six hours against the official test dose of the standard toxin. The test dose is 100 minimal lethal doses of a precipitated toxin preserved under special conditions at the Hygienic Laboratory of the Public Health and Marine-Hospital Service. It was decided that the minimal immunizing dose for a case of possible infection through a wound should be 1,500 of such units. It was decided that after April 1 the new unit should be adopted by all producers of tetanus antitoxin.
>
> J. J. Kinyoun, *Chairman.*
> Herbert D. Pease,
> Joseph McFarland,
> Theobald Smith,
> E. M. Houghton,
> M. J. Rosenau,
> William H. Park, *Secretary.*

In this method the immunity unit for measuring the strength of tetanus antitoxin is fixed so that it shall be ten times the least quantity of antitoxin serum necessary to save the life of a 350-gram guinea pig for ninety-six hours against the official test dose of a standard toxin furnished by the Hygienic Laboratory of the Public Health and Marine-Hospital Service.

Thus it is required from the manufacturers of the "human" tetanus antitoxin to state the number of units their products contain, which not only insures serum of reliable strength, but also establishes a uniformity among the producers of tetanus antitoxin in America. On the other hand, the antitoxins destined for "veterinary" use are still under no control whatsoever; there is no uniformity in the method of standardization, and the potency of the product is absolutely left to the honesty of the manufacturer. This state of affairs of course does not assure the veterinarian of any uniformity of the product even of the same manufacturer, still less of different manufacturers. Only one of the different veterinary tetanus antitoxins on the market states the number of American units the immunizing or curative dose contains. The others fail to make any declaration, and in one case the number of units is given in the hundred thousands, whereas the human antitoxin of the same firm of course complies with the requirements of the law, stating definitely the number of American units that particular antitoxin contains. These conditions alone should suffice to point out the necessity for supervision of this veterinary product and the establishment of uniformity among the producers of veterinary antitoxin. It is very essential that the veterinarian should have some assurance of the strength of the antitoxin upon which his standing as a professional man may depend.

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[a] Rosenau and Anderson. The standardization of tetanus antitoxin. Bulletin 43, Hygienic Laboratory, U. S. Public Health and Marine-Hospital Service. Washington, 1908.

### EXAMINATION OF COMMERCIAL VETERINARY ANTITOXINS.

The samples of tetanus antitoxin (veterinary) which were standardized in connection with this work were obtained from various drug stores in Chicago, New York, and Washington. They were kept at a temperature from 50° to 60° C. until the tests were made, care being taken not to expose them to any condition which might affect the potency of the antitoxin.

The toxin was obtained from the Hygienic Laboratory of the Public Health and Marine-Hospital Service through the courtesy of Surgeon-General Walter Wyman, and represented the dried standard toxin which is used in the standardization of tetanus antitoxin in the Hygienic Laboratory and furnished to the manufacturers of antitoxin. In the determination of the value of the antitoxin the L+ dose is the test dose of the toxin. The L+ dose is the smallest quantity of tetanus toxin that will neutralize one-tenth of an immunity unit, plus a quantity of toxin sufficient to kill an animal in just four days. The L+ dose of the toxin which was used in these tests contained 100 minimal lethal doses (MLD) for a 350-gram guinea pig. The toxin was kept in a dark, cold place and during the course of these tests its virulence was controlled by repeated tests with an antitoxin of known value.

The guinea pigs used in connection with this standardization were carefully selected, being vigorously healthy animals of from 350 to 370 grams in weight. The glassware employed in the work was selected according to the recommendation of Rosenau, and was not used for any other purpose. The mixing cylinders and mixing flasks were the kind designed by Rosenau. Ehrlich's delivery pipettes graduated into hundredths, as well as special delivery and capacity pipettes, were used. The syringes employed were a modification of the old Koch syringe, in which the barrel tapers gradually to the needle, so that the last drop runs out readily.

The necessary measures against bacterial contamination were taken during the execution of the work. All the glassware was first rendered chemically clean and then sterilized for one hour at 120° C. All the various steps in the procedure were followed carefully in order that the results would be accurate and reliable. The method of the standardization was executed in every particular as described by Rosenau and Anderson in Bulletin 43 of the Hygienic Laboratory.

The number of immunity units contained in a cubic centimeter of serum is determined by the quantity of antitoxin which saved the life of a guinea pig for ninety-six hours against the official test dose of the toxin. This quantity of antitoxin represents one-tenth of an immunity unit. For instance, if a guinea pig receiving 0.0015 c. c. of the antitoxin with the official test dose of toxin is saved for ninety-six hours, this quantity of antitoxin contains one-tenth of an immunity unit. Accordingly, the following equation is represented: $0.0015 : 0.1 :: 1 : x$, which indicates that 1 cubic centimeter of the serum contains 66 units.

In the following tables are given the results of the standardization obtained from the tests of the various samples of veterinary tetanus antitoxin examined in this laboratory:

TABLE 1.—*H. K. Mulford Company's Tetanus Antitoxin Serum for veterinary use. Immunizing dose, labeled to contain 500,000 units. To be exchanged after May 1, 1910. Laboratory No. 2960. Syringe contained 7.6 c. c.*

| No. of guinea pig. | Subcutaneous injection. | | Time of death or effect of injection. | Antitoxin units. | |
|---|---|---|---|---|---|
| | Toxin. | Anti-toxin. | | Number per cubic centimeter. | Total number in syringe. |
| | *c. c.* | *c. c.* | | | |
| 1 | 0.0006 | 0.0010 | 1 day, 20 hours. | | |
| 2 | .0006 | .0011 | 1 day, 26 hours. | | |
| 3 | .0006 | .0012 | 3 days, 19 hours. | | |
| 4 | .0006 | .0013 | 5 days, 22 hours | 81 | 615 |
| 5 | .0006 | .0014 | Symptoms. | | |
| 6 | .0006 | .0015 | No symptoms. | | |
| 7 | .0006 | .0020 | Do. | | |
| 8 | .0006 | .0025 | Do. | | |
| 9 | .0006 | .0030 | Do. | | |

TABLE 2.—*Parke, Davis & Co.'s Antitetanic Serum (veterinary). To be exchanged after November 24, 1910. Unit value not stated. Syringe contained 10 c. c.*

| No. of guinea pig. | Subcutaneous injection. | | Time of death or effect of injection. | Antitoxin units. | |
|---|---|---|---|---|---|
| | Toxin. | Antitoxin. | | Number per cubic centimeter. | Total number in syringe. |
| | c. c. | c. c. | | | |
| 1 | 0.0006 | 0.0006 | 1 day, 12 hours. | | |
| 2 | .0006 | .0007 | 3 days, 7 hours. | | |
| 3 | .0006 | .0008 | 4 days, 12 hours | 125 | 1,250 |
| 4 | .0006 | .0009 | Symptoms. | | |
| 5 | .0006 | .0010 | Slight symptoms. | | |
| 6 | .0006 | .0015 | No symptoms. | | |
| 7 | .0006 | .0020 | Do. | | |
| 8 | .0006 | .0025 | Do. | | |
| 9 | .0006 | .0030 | Do. | | |

TABLE 3.—*H. K. Mulford Company's Tetanus Antitoxin Serum for veterinary use. Immunizing dose, labeled to contain 500,000 units. To be exchanged May 15, 1910. Laboratory No. 2960. Syringe contained 7.5 c. c.*

| No. of guinea pig. | Subcutaneous injection. | | Time of death or effect of injection. | Antitoxin units. | |
|---|---|---|---|---|---|
| | Toxin. | Antitoxin. | | Number per cubic centimeter. | Total number in syringe. |
| | c. c. | c. c. | | | |
| 1 | 0.0006 | 0.0010 | 2 days, 12 hours. | | |
| 2 | .0006 | .0013 | 4 days, 7 hours | 81 | 607 |
| 3 | .0006 | .0016 | 6 days, 8 hours. | | |
| 4 | .0006 | .0019 | Slight symptoms. | | |
| 5 | .0006 | .0022 | No symptoms. | | |

TABLE 4.—*Pasteur Laboratories, Paris, France, Antitetanic Serum for veterinary use. Unit value not stated. Bottle contained 10 c. c.*

| No. of guinea pig. | Subcutaneous injection. | | Time of death or effect of injection. | Antitoxin units. | |
|---|---|---|---|---|---|
| | Toxin. | Antitoxin. | | Number per cubic centimeter. | Total number in bottle. |
| | c. c. | c. c. | | | |
| 1 | 0.0006 | 0.0010 | 4 days, 2 hours | 100 | 1,000 |
| 2 | .0006 | .0013 | Slight symptoms. | | |
| 3 | .0006 | .0016 | No symptoms. | | |
| 4 | .0006 | .0019 | Do. | | |
| 5 | .0006 | .0022 | Do. | | |

TABLE 5.—*Lederle Antitoxin Laboratories, Tetanus Antitoxin (veterinary). Immunizing dose, labeled to contain 1,500 units. Laboratory No. 19A. To be exchanged June 21, 1910. Syringe contained 10.4 c. c.*

| No. of guinea pig. | Subcutaneous injection. | | Time of death or effect of injection. | Antitoxin units. | |
|---|---|---|---|---|---|
| | Toxin. | Antitoxin. | | Number per cubic centimeter. | Total number in syringe. |
| | *c. c.* | *c. c.* | | | |
| 1 | 0.0006 | 0.00035 | 1 day, 18 hours. | | |
| 2 | .0006 | .00050 | 1 day, 15 hours. | | |
| 3 | .0006 | .00065 | 4 days, 3 hours | 154 | 1,601 |
| 4 | .0006 | .00080 | Symptoms. | | |
| 5 | .0006 | .00085 | No symptoms. | | |

TABLE 6.—*Parke, Davis & Co's Antitetanic Serum (veterinary). To be exchanged after December 8, 1910. Unit value not stated. Syringe contained 10 c. c.*

| No. of guinea pig. | Subcutaneous injection. | | Time of death or effect of injection. | Antitoxin units. | |
|---|---|---|---|---|---|
| | Toxin. | Antitoxin. | | Number per cubic centimeter. | Total number in syringe. |
| | *c. c.* | *c. c.* | | | |
| 1 | 0.0006 | 0.0005 | 3 days, 1 hour. | | |
| 2 | .0006 | .0008 | 5 days, 20 hours | 125 | 1,250 |
| 3 | .0006 | .0011 | No symptoms. | | |
| 4 | .0006 | .0014 | Do. | | |
| 5 | .0006 | .0017 | Do. | | |

TABLE 7.—*Parke, Davis & Co's Antitetanic Serum (veterinary). To be exchanged after December 8, 1910. Unit value not stated. Syringe contained 10 c. c.*

| No. of guinea pig. | Subcutaneous injection. | | Time of death or effect of injection. | Antitoxin units. | |
|---|---|---|---|---|---|
| | Toxin. | Antitoxin. | | Number per cubic centimeter. | Total number in syringe. |
| | *c. c.* | *c. c.* | | | |
| 1 | 0.0006 | 0.0005 | 2 days, 21 hours. | | |
| 2 | .6006 | .0008 | Symptoms | 125 | 1,250 |
| 3 | .0006 | .0011 | Slight symptoms. | | |
| 4 | .0006 | .0014 | No symptoms. | | |
| 5 | .0006 | .0017 | | | |

TABLE 8.—*Parke, Davis & Co's Antitetanic Serum (veterinary). To be exchanged after January 14, 1911. Unit value not stated. Syringe contained 10 c. c.*

| No. of guinea pig. | Subcutaneous injection. | | Time of death or effect of injection. | Antitoxin units. | |
|---|---|---|---|---|---|
| | Toxin. | Antitoxin. | | Number per cubic centimeter. | Total number in syringe. |
| | *c. c.* | *c. c.* | | | |
| 1 | 0.0006 | 0.0010 | 4 days, 5 hours | 100 | 1,000 |
| 2 | .0006 | .0014 | Slight symptoms. | | |
| 3 | .0006 | .0018 | No symptoms. | | |
| 4 | .0006 | .0022 | Do. | | |
| 5 | .0006 | .0026 | Do. | | |

TABLE 9.—*H. K. Mulford Company's Tetanus Antitoxin Serum for veterinary use. Immunizing dose, labeled to contain 500,000 units. To be exchanged after May 15, 1910. Laboratory No. 2971. Syringe contained 8 c. c.*

| No. of guinea pig. | Subcutaneous injection. | | Time of death or effect of injection. | Antitoxin units. | |
|---|---|---|---|---|---|
| | Toxin. | Antitoxin. | | Number per cubic centimeter. | Total number in syringe. |
| | *c. c.* | *c. c.* | | | |
| 1 | 0.0006 | 0.0008 | 2 days, 1 hour. | | |
| 2 | .0006 | .0011 | 2 days, 18 hours. | | |
| 3 | .0006 | .0014 | 2 days, 23 hours. | | |
| 4 | .0006 | .0017 | 6 days, 4 hours | 59 | 472 |
| 5 | .0006 | .0020 | Slight symptoms. | | |

TABLE 10.—*Pasteur Laboratories, Paris, France, Antitetanic Serum for veterinary use. Unit value not stated. Bottle contained 10 c. c.*

| No. of guinea pig. | Subcutaneous injection. | | Time of death or effect of injection. | Antitoxin units. | |
|---|---|---|---|---|---|
| | Toxin. | Antitoxin. | | Number per cubic centimeter. | Total number in bottle. |
| | *c. c.* | *c. c.* | | | |
| 1 | 0.0006 | 0.0006 | 2 days, 20 hours. | | |
| 2 | .0006 | .0009 | 6 days, 7 hours | 111 | 1,110 |
| 3 | .0006 | .0012 | Symptoms. | | |
| 4 | .0006 | .0015 | No symptoms. | | |
| 5 | .0006 | .0018 | Do. | | |

Table 11.—*Pasteur Laboratories, Paris, France, Antitetanic Serum for veterinary use. Unit value not stated. Bottle contained 10 c. c.*

| No. of guinea pig. | Subcutaneous injection. | | Time of death or effect of injection. | Antitoxin units. | |
|---|---|---|---|---|---|
| | Toxin. | Antitoxin. | | Number per cubic centimeter. | Total number in bottle. |
| | *c. c.* | *c. c.* | | | |
| 1 | 0.0006 | 0.00050 | 3 days, 6 hours. | 153 | 1,530 |
| 2 | .0006 | .00065 | 4 days, 18 hours | | |
| 3 | .0006 | .00080 | No symptoms. | | |
| 4 | .0006 | .00095 | Do. | | |
| 5 | .0006 | .00110 | Do. | | |

Table 12.—*H. K. Mulford Company's Tetanus Antitoxin Serum for veterinary use. Immunizing dose, labeled to contain 500,000 units. To be exchanged after May 1, 1910. Laboratory No. 2,960. Syringe contained 7.5 c. c.*

| No. of guinea pig. | Subcutaneous injection. | | Time of death or effect of injection. | Antitoxin units. | |
|---|---|---|---|---|---|
| | Toxin. | Antitoxin. | | Number per cubic centimeter. | Total number in syringe. |
| | *c. c.* | *c. c.* | | | |
| 1 | 0.0006 | 0.0007 | 1 day 14 hours. | 81 | 607 |
| 2 | .0006 | .0010 | 3 days 7 hours. | | |
| 3 | .0006 | .0013 | Symptoms | | |
| 4 | .0006 | .0016 | No symptoms. | | |
| 5 | .0006 | .0019 | Do. | | |

Table 13.—*Lederle Antitoxin Laboratories, Tetanus Antitoxin (veterinary). Immunizing dose, labeled to contain 1,500 units. Laboratory No. 19A. To be exchanged June 21, 1910. Syringe contained 8.5 c. c.*

| No. of guinea pig. | Subcutaneous injection. | | Time of death or effect of injection. | Antitoxin units. | |
|---|---|---|---|---|---|
| | Toxin. | Antitoxin. | | Number per cubic centimeter. | Total number in syringe. |
| | *c. c.* | *c. c.* | | | |
| 1 | 0.0006 | 0.00024 | 1 day 16 hours. | 232 | 1,972 |
| 2 | .0006 | .0003333 | 2 days 22 hours. | | |
| 3 | .0006 | .00043 | Symptoms | | |
| 4 | .0006 | .00053 | No symptoms. | | |
| 5 | .0006 | .00060 | Do. | | |

TABLE 14.—*Pasteur Laboratories, Paris, France, Antitetanic Serum for veterinary use. Unit value not stated. Bottle contained 10 c. c.*

| No. of guinea pig. | Subcutaneous injection. |  | Time of death or effect of injection. | Antitoxin units. |  |
|---|---|---|---|---|---|
|  | Toxin. | Antitoxin. |  | Number per cubic centimeter. | Total number in bottle. |
|  | c. c. | c. c. |  |  |  |
| 1 | 0.0006 | 0.00035 | 1 day 14 hours. |  |  |
| 2 | .0006 | .00050 | 2 days 20 hours. |  |  |
| 3 | .0006 | .00065 | 4 days 5 hours | 153 | 1,530 |
| 4 | .0006 | .00080 | 4 days 16 hours. |  |  |
| 5 | .0006 | .00095 | Slight symptoms. |  |  |

The results of these tests clearly demonstrate the variations in the potency of veterinary tetanus antitoxins at present on the market. While the preparations of the individual manufacturers do not show such marked differences in strength, yet they do not uniformly contain a sufficient number of units.

In accordance with the law of 1902, the manufacturers of human antitoxins are required to state on the labels of the packages the number of units that the particular antitoxin possesses. Should it be found on investigation that the antitoxin does not come to within 10 per cent of the strength stated on the labels, the manufacturer is immediately required to recall from the market all that particular antitoxin. Thus, if a physician intends to use the antitoxin either for immunizing purposes or as a curative agent, he is accurately guided in the dose by the statement on the label. It does not matter who the manufacturer of the antitoxin is. This latter fact is in itself also of great importance, as frequently the drug stores carry antitoxins of only one or two manufacturers.

On the other hand, the veterinarian has not always the good fortune of knowing the number of units that an antitoxin which he purchases contains. Only one of the manufacturers states on the label the number of American units contained in his veterinary antitoxin. One other manufacturer still uses for his veterinary antitoxin a standardization—other than American—by which he can label his product in the hundred thousands, yet his antitoxin for the human gives the units in the American standard. Why should two different standards be maintained, one for the human and the other for veterinary antitoxin?

The veterinary tetanus antitoxins are marketed in immunizing doses and curative doses. The immunizing dose is supposed to contain 1,500 American units. The volumetric quantity of this dose was found to be accurately 10 c. c. in the Parke, Davis & Co. and the Pasteur product, while the Lederle serum contained from 8.5 c. c. to 10.4 c. c. and the Mulford syringe from 7.5 to 8 c. c. Now, should it be desired to administer to a horse an immunizing dose of the antitoxin it can readily be seen from the results obtained in these tests, as indicated by the tables, that while the immunizing dose of some of the serums contains the desired 1,500 units, others, on the other hand, possess less than one-third of that strength. For instance, according to the test shown by Table 9, the syringe contained 8 c. c. of serum with 59 units per cubic centimeter; thus the immunizing dose in this case represents only 472 units, and of course the curative dose is correspondingly low. This alone is sufficient to indicate the urgent necessity for some uniformity in standardizing the veterinary antitoxins, and also for Federal legislation by which they could be subjected to a periodical control with reference to their potency.

Under the present conditions there is the constant uncertainty regarding the strength of the serum, as the veterinarian has no assurance whatever of its potency, and is solely dependent on the reliability of the manufacturer.

## CONCLUSIONS.

1. The veterinary tetanus antitoxins prepared by the different manufacturers have not a uniform potency, and the variation amounts in some instances to about two-thirds less than the strength which it should possess.
2. In order to insure a uniform strength, the manufacturers of veterinary tetanus antitoxins should be required to use the American standard, and to state on the label the number of American units the dose contains, as is required for human tetanus antitoxin.
3. The immunizing dose for a horse should contain at least 1,500 immunity units of the standard established by the United States Public Health and Marine-Hospital Service.
4. It is seen that the veterinary tetanus antitoxins vary extravagantly in the unit strength, and some are comparatively weak in antitoxic potency, which shows the necessity for the same supervision by the United States Department of Agriculture over biological products used in veterinary medicine as is now exercised by the United States Public Health and Marine-Hospital Service over similar products used in human medicine.
5. The request for such supervision should have the indorsement of the veterinarians and live-stock interests of this country.

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# FACTORS CONTROLLING THE MOISTURE CONTENT OF CHEESE CURDS.

BY

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# LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF ANIMAL INDUSTRY,
*Washington, D. C., February 15, 1910.*

SIR: I have the honor to transmit, and to recommend for publication in the bulletin series of this Bureau, the accompanying manuscript entitled "Factors Controlling the Moisture Content of Cheese Curds," by J. L. Sammis, of the Wisconsin Agricultural Experiment Station, and S. K. Suzuki and F. W. Laabs, of the Dairy Division of this Bureau, this being a report of a part of the cooperative investigations in cheese making which are in progress at the Wisconsin Experiment Station between that Station and this Bureau.

The problem of controlling the moisture content of cheese curds in the vat is one of much importance to the modern cheese maker, and the methods used in the experiments reported in this paper were specially planned to meet practical conditions. It is hoped that the results and conclusions will be of value to the cheese-making industry as well as to teachers and students in this line of work.

Respectfully,

A. D. MELVIN,
*Chief of Bureau.*

Hon. JAMES WILSON,
*Secretary of Agriculture.*

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# FACTORS CONTROLLING THE MOISTURE CONTENT OF CHEESE CURDS.

## INTRODUCTION.

In the cheese-making industry some practically exact methods of measuring the conditions have already come into general use. The thermometer has replaced the hand as an instrument for measuring temperature; the rennet tests devised by Marschall, Monrad, and Harris have replaced the senses of taste and smell as means for measuring acidity of milk in the cheese vat; and the standard alkaline solution for measuring acidity is coming into general use among careful cheese makers. The latter is applied to the milk, whey, or drainings from the curd at every stage of the process as long as the curd is in the vat. When following the development of acid in the cheese vat with any form of acidimeter, it is commonly the practice to add rennet to the milk when the acidity is about 0.18 per cent; to draw the whey and mat the curd when the whey acidity is about 0.17 per cent, so that, after stirring, the drippings titrate 0.24 to 0.30 per cent; to mill the curd when the drippings titrate 0.65 to 0.90 per cent; and to salt the curd when the acidity of the drippings has reached 0.90 to 1.2 per cent.[a]

No less important than acidity in its effect on the quality of the finished cheese is the moisture content. Throughout the process of making cheese, while in the vat, the effort is made to establish and maintain a proper relationship between the moisture and acid content of the curd.[b]

After the starter has been added and the vat heated little more can be done to either hasten or delay the bacterial development of acid. Therefore it is customary to watch the increase of acidity by using an acidimeter or rennet test, and to vary the operations which affect the moisture content to suit the observed rate of acid development. The following quotations express ideas which are prevalent to-day among cheese makers, and describe the methods used in Cheddar cheese factories in judging the moisture content of a curd. Decker[a] says:

---

[a] Van Slyke, Lucius L., and Publow, Charles L. The science and practice of cheese making. New York, 1909. Pp. 31-37.

[b] Loc. cit., p. 45.

> When the whey is drawn, the curd must not be salvy and soft; but when a big double handful is pressed together in the hands and one hand removed it should not remain in a mashed-up mass, but should fall apart readily.

Efforts to develop a simple, rapid method of judging the moisture content more accurately than can be done by the feeling have been made at this station and at the Ontario Agricultural College.[b] Of late various rapid moisture tests for butter and cheese have been devised and placed on the market, but none as yet have come into general use in cheese factories. It is difficult to teach students to judge when curd is firm enough to be dipped by feeling it, and experienced makers do not always agree on this point.

The experience of practical cheese makers has shown that certain operations can be used with success for the purpose of more rapidly separating whey from curd when speed is necessary. On account of the crudeness of the method employed in judging these effects, namely, by the feeling of the curd when grasped, it is impossible to state at present which of the various contributing agencies is the most efficient in producing the desired result. It is difficult to understand these matters in the absence of more exact information respecting changes in the moisture content than can be obtained by squeezing the curd in the hand at various stages of the cheese-making process. On this point Van Slyke and Publow[c] say:

> The contraction or hardening of the pieces of curd is known as "firming." It is probably due primarily to escape of whey. What share temperature, rennet, and acidity each has in the process can not now be stated definitely.

Some determinations of moisture in curds in the vat at one stage or another are recorded in the literature on this subject, notably by Professor Dean in the Annual Reports of the Ontario Agricultural College and Experimental Farm, but a systematic and intimate study of the entire subject has not been reported.

## PLAN OF PRESENT INVESTIGATIONS.

In view of what has been stated it was decided to make cheese under various well-defined conditions, to take samples of the curds at short intervals of time throughout the process of making, and to determine the moisture by drying and weighing. It was hoped to obtain more exact information respecting practical methods of controlling the moisture content of cheese by this means than has been heretofore available. The results are presented in a form which can be readily used by teachers and students of cheese making.

---

[a] Decker, John W. Cheese making. Fifth revised edition, by F. W. Woll. Madison, Wis., 1909. Pp. 62-63.

[b] Dean, Henry H. A short test for determining the moisture in curd at dipping. Ontario Agricultural College and Experimental Farm, Thirty-second Annual Report, 1906, pp. 123-125. Toronto, 1907.

[c] Loc. cit., p. 27.

The work includes a study of the following important factors in cheese making: (1) Temperature; (2) size of cubes; (3) proportion of rennet; (4) acidity; (5) pressure; (6) proportions of fat and water in milk.

## METHODS USED IN MAKING THE EXPERIMENTAL CHEESE.

The general plan was to make cheese in several small vats at the same time from equal weighed quantities of mixed milk. The milk in the large receiving vat was stirred steadily while portions were being drawn therefrom. The vats and apparatus were some of those used in giving instruction to large classes of students in cheese making.

In experimental work, where several vats of milk are to be handled simultaneously in accordance with prearranged plans, it is necessary to use smaller quantities of milk than would commonly be contained in a factory vat. The point where experimenters sometimes fail is in attempting to handle such large quantities of materials in an experiment that it is impossible to carry out with thoroughness the operations planned. It is believed that the quantity of milk used by us, usually 200 pounds in each vat, as well as the other conditions in the experiments described, were such that the work could be done with a high degree of accuracy, and that the results can properly be regarded as illustrating the principles involved in cheese-factory operations, whether conducted on a large or a small scale.

The four vats were handled daily by two operators, and, unless otherwise stated, were heated and set with rennet at 86° F. at intervals of five or ten minutes. The curds were cut in a uniform manner into one-half inch cubes, and heat was turned on fifteen minutes after cutting. The rate of raising the temperature was carefully equalized, and the steam was turned off thirty-five minutes after cutting. The whey was drawn two and one-half hours or more after cutting, and the curds were scooped onto racks. They were usually not stirred on the rack, and were kept at the desired temperature by warm water placed in the lower end of the vats. A curd mill was used, and 2½ pounds of salt was added for each 100 pounds of curd.

Rennet extract was measured accurately in a cylinder or graduated pipette. The thermometers employed were carefully compared with a standard instrument, and did not differ over one-half of a degree Fahrenheit.

The temperatures observed in cheese-making experiments are stated in terms of the Fahrenheit scale, since this is generally used in Cheddar cheese factories. Chemical analyses are described in terms of the Centigrade scale.

The time when each operation was performed and when each sample was taken was recorded as the work proceeded. Each day one part of the process was varied in the different vats, all other parts being performed alike.

## METHODS OF DETERMINING MOISTURE.

To determine how the moisture content of the four curds differed, samples of each were taken at intervals of five, fifteen, thirty, or sixty minutes, as required, throughout the process. So long as the curds were in the whey the sampling of the curds was done by the use of a small dipper 3 inches in diameter and 1 inch deep, with a wire-strainer-cloth bottom. This was inserted to the bottom of the vat and lifted out after the entire vat contents had been set in motion by vigorously stirring with the hands. The samples thus obtained were freed from superficial moisture by placing them for a moment on sheets of filter paper, and then were quickly weighed in 10-gram portions into numbered tin boxes, which, with their covers and a small quantity of dried sand, weighed exactly 17 grams each. Curds out of the whey were sampled by inserting a long, sharp-edged brass sampling tube, and were not dried on paper. A balance sensitive to 0.005 gram was used in weighing samples. Duplicate moisture determinations were made on each sample of curd, and the results are given in the tables. The dishes of curd prepared each day were placed together on perforated metal trays in a double-walled cast-iron drying oven, heated with steam, which has been described elsewhere.[a]

Having in the oven 60 to 80 10-gram samples of curd, containing about 50 per cent of moisture, the weight of water to be evaporated was something like 300 grams. The oven door was opened at intervals during the first three hours to let the water vapor escape freely. The steam pressure being 45 to 50 pounds the temperature inside the oven stood at 110° to 120° C. during the first four hours, while most of the water was being evaporated, and later rose to 130°. It is best to weigh two or three dishes from the lot each day after four, six, and eight hours' heating, returning them to the oven between weighings, and to remove the entire lot of dishes from the oven after it has been demonstrated that loss of weight has practically ceased. When the oven contains only a few dishes the drying proceeds more rapidly. The perforated metal trays used to support the dishes permit free circulation of air within the oven. An arrangement for admitting previously heated air at the bottom, with an exit at the top, would probably shorten the time required for drying cheese samples to constant weight.

---

[a] Farrington, E. H. A creamery method for the determination of water in butter. Wisconsin Agricultural Experiment Station, Bulletin 154, Madison, 1907.

Comparison was made between the high-pressure oven and a sheet-copper drying oven heated by live steam from the heating system reduced to atmospheric pressure by a reducing valve. The temperature stood at 90° C. Eight dishes, each containing 10 grams of a well-mixed curd sample, were placed in these 2 ovens, 4 in each. In the high-temperature oven there were also placed at the same time 56 other dishes of curd. The 8 dishes were removed from the ovens at intervals, the lids put on each time, and the dishes weighed when cool and immediately returned to the ovens. Table 1 shows that the loss in weight practically ceased in eight hours at 44.8 per cent loss in the high-temperature oven, and in one hundred and twenty hours at 44.4 per cent loss in the low-temperature oven. The latter would, no doubt, have come to constant weight sooner if the temperature had been nearer 100° C. From this it is concluded that the drying of curds for eight hours in the oven, heated by steam at 45 to 50 pounds pressure, gives practically correct results. Accordingly this oven was used in all of the following experiments, and the results are strictly comparable with each other.

TABLE 1.—*Loss of weight from curds when dried in the high and low temperature ovens.*

| Total time heated. | | Total loss in weight. | | Loss in weight per hour. | |
|---|---|---|---|---|---|
| | | High temperature. | Low temperature. | High temperature. | Low temperature. |
| *Hrs.* | *m.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 2 | 0 | 24.30 | 16.20 | 12.10 | 8.1 |
| 3 | 40 | 40.95 | 21.50 | 10.00 | 3.2 |
| 4 | 30 | 44.20 | 26.40 | 3.30 | 5.0 |
| 5 | 50 | 44.60 | 30.10 | .30 | 3.0 |
| 8 | 50 | 44.80 | 35.40 | .07 | 1.8 |
| 10 | 35 | 44.80 | 38.10 | ............ | 1.3 |
| 27 | 25 | 44.90 | 42.40 | .005 | .25 |
| 49 | 0 | ............ | 43.30 | ............ | .04 |
| 65 | 0 | ............ | 44.00 | ............ | .04 |
| 74 | 0 | ............ | 44.15 | ............ | .016 |
| 98 | 0 | ............ | 44.30 | ............ | .006 |
| 122 | 0 | ............ | 44.40 | ............ | .004 |
| 266 | 0 | ............ | 44.50 | ............ | .0007 |

## MOISTURE CONTENT OF FOUR SIMILAR CURDS, SHOWING ACCURACY OF METHOD.

The degree of accuracy attainable under the prevailing conditions was determined, on several days, by handling the vats as nearly alike as possible and determining the moisture content of the four curds at regular intervals.

The following experiment is described because it shows the largest variations between duplicate vats which were observed at any time;

in the succeeding pages the agreement of results between different vats is closer in several cases. The milk had 4 per cent fat and 0.185 per cent acid when set. The curds were not stirred on the rack. The acidity of the whey when drawn was 0.205 per cent. The curds were dipped two and one-half hours, milled four hours, salted six hours, and hooped six hours and twenty minutes after cutting. The temperature in all vats when set was 86° F.; thirty-five minutes after cutting it was 104° F., and the same when the whey was drawn. The curds were milled at 100°, salted at 90°, and hooped at 85°. In Table 2, and in all the following tables, the moisture content of the curd when cut is given as 87 per cent, this figure being assumed and not determined by anlaysis.

TABLE 2.—*Moisture content of four curds made in different vats from mixed milk.*

| Time after cutting. | | Moisture in curd. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Vat I. | | | Vat II. | | | Vat III. | | | Vat IV. | | |
| *Hrs.* | *m.* | *P. ct.* | *P. ct.* | *Average per cent.* | *P. ct.* | *P. ct.* | *Average per cent.* | *P. ct.* | *P. ct.* | *Average per cent.* | *P. ct.* | *P. ct.* | *Average per cent.* |
| 0 | 0 | ...... | ...... | 87.0 | ...... | ...... | 87.0 | ...... | ...... | 87.0 | ...... | ...... | 87.0 |
| 0 | 30 | 78.2 | 78.4 | 78.3 | 77.7 | 77.8 | 77.8 | 80.0 | 78.7 | 79.8 | 79.0 | 79.0 | 79.0 |
| 1 | 0 | 67.7 | 67.6 | 67.6 | 67.5 | 67.5 | 67.5 | 66.5 | 65.8 | 66.2 | 67.1 | 66.5 | 67.3 |
| 1 | 30 | 61.4 | 61.5 | 61.5 | 63.6 | 64.1 | 63.9 | 61.5 | 61.8 | 61.7 | 61.1 | 60.5 | 60.8 |
| 2 | 30 | 55.9 | 55.9 | 55.9 | 56.8 | 55.8 | 56.3 | 54.2 | 56.0 | 55.1 | 54.9 | 54.4 | 54.7 |
| 3 | 0 | 45.6 | 45.6 | 45.6 | 44.9 | 45.3 | 45.1 | 46.2 | 45.4 | 45.8 | 44.0 | 43.8 | 43.9 |
| 4 | 0 | 41.0 | 41.2 | 41.1 | 42.1 | 42.7 | 42.4 | 41.1 | 40.7 | 40.9 | 41.3 | 42.0 | 41.7 |
| 6 | 0 | 38.9 | 39.1 | 39.0 | 38.6 | 39.6 | 39.1 | 38.8 | 39.2 | 39.0 | 38.9 | 39.0 | 39.0 |
| 6 | 20 | 35.8 | 36.0 | 35.9 | 37.0 | 37.1 | 37.0 | 36.3 | 36.3 | 36.3 | 36.5 | 37.1 | 36.8 |

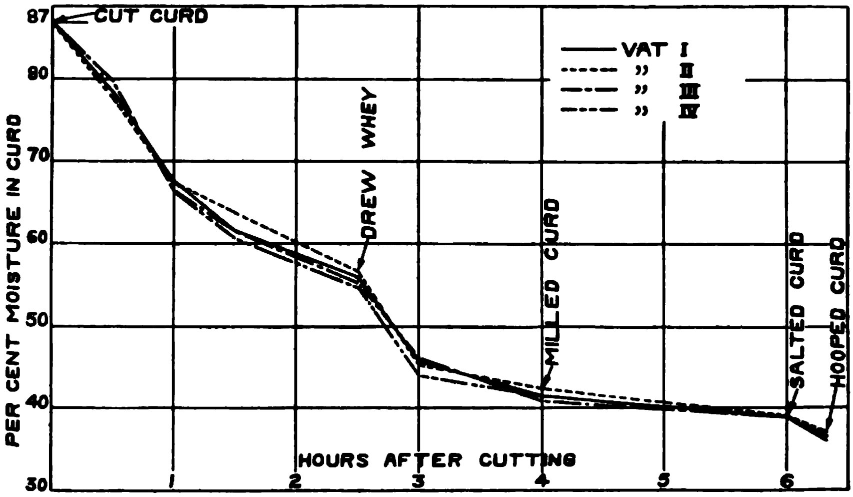

FIG. 1.—Curves showing experimental errors in determining the moisture content of four duplicate curds.

If we regard the average of two determinations as representing correctly the moisture content of the curd, it is seen in the experiment just described that the departure of any curd from the average moisture content of the four curds at the same time is, on the average, 0.53 per cent of the weight of the curd. In the same experiment the departure of any single moisture determination from the average of the pair is, on the average, 0.20 per cent of the weight of the sample.

The duplicate moisture determinations agree better with each other than do the four curds among themselves. The accurate sampling of curd in a vat is probably much more difficult than the determination of moisture in the samples. (See fig. 1.)

### ACCURACY OF SAMPLING OF CURD IN THE VAT.

In all the experiments described one sample was taken from a vat at a time, and from each sample two portions of 10 grams each were weighed into tin dishes. To see how close an agreement could be had between the moisture content of samples taken from the vat in rapid succession, samples were drawn every five minutes during a two-hour period, previous to drawing the whey. The analytical data are given in Table 3. From this it can be seen that the methods used gave fairly satisfactory and uniform samples. The variations between successive samples are small. The departure of a moisture determination from the average of the pair was in this experiment 0.47 per cent of the weight of the curd, on the average, among the entire 30 samples. The average among the first 15 samples was 0.61 per cent, and among the last 15 samples 0.33 per cent, showing that the curds can be sampled with less difficulty and error during the later stages of the cheese-making process. The unavoidable variations observed in these preliminary experiments were smaller than the variations of moisture content which resulted from intentional modification of the cheese-making process, as shown in subsequent experiments. The acidity of the milk was 0.16 per cent when set, and the whey showed 0.125 per cent acidity when drawn, two and one-half hours after cutting. (See fig. 2.)

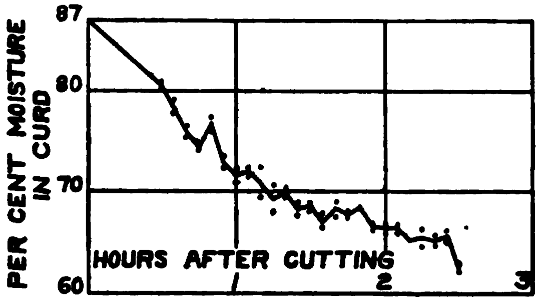

FIG. 2.—Duplicate moisture determinations to show accuracy of sampling. The two determinations (shown by lines of dots) and the averages (shown by solid line) indicate the degree of accuracy attained.

TABLE 3.—*Moisture in samples taken at five-minute intervals to determine accuracy of the method of sampling.*

| Time after cutting. | Moisture found. | | | Time after cutting. | Moisture found. | | |
|---|---|---|---|---|---|---|---|
| *Hrs. m.* | *Per cent.* | *Per cent.* | *Average per cent.* | *Hrs. m.* | *Per cent.* | *Per cent.* | *Average per cent.* |
| 0 30 | 80.6 | 80.2 | 80.4 | 1 45 | 67.6 | 67.9 | 67.8 |
| 0 35 | 77.9 | 79.1 | 78.5 | 1 50 | 68.2 | 68.5 | 68.4 |
| 0 40 | 75.5 | 76.3 | 75.9 | 1 55 | 66.7 | 66.3 | 66.5 |
| 0 45 | 74.1 | 74.3 | 74.2 | 2 00 | 65.7 | 66.6 | 66.2 |
| 0 50 | 76.3 | 77.5 | 76.9 | 2 05 | 66.0 | 66.6 | 66.3 |
| 0 55 | 72.5 | 73.3 | 72.9 | 2 10 | 65.1 | 65.1 | 65.1 |
| 1 0 | 70.9 | 72.2 | 71.5 | 2 15 | 64.4 | 66.3 | 65.3 |
| 1 5 | 71.6 | 72.3 | 71.9 | 2 20 | 64.7 | 65.6 | 65.1 |
| 1 10 | 69.3 | 72.4 | 70.8 | 2 25 | 65.1 | 66.3 | 65.6 |
| 1 15 | 67.7 | 70.5 | 69.1 | 2 30 | 62.1 | 62.8 | 62.4 |
| 1 20 | 69.7 | 70.2 | 69.9 | 3 0 | 50.8 | 50.8 | 50.8 |
| 1 25 | 67.4 | 68.7 | 68.1 | 3 30 | 45.8 | 46.6 | 46.2 |
| 1 30 | 68.1 | 68.7 | 68.4 | 4 0 | 43.7 | 43.9 | 43.8 |
| 1 35 | 66.3 | 67.7 | 67.0 | 4 30 | 40.1 | 41.6 | 40.8 |
| 1 40 | 67.4 | 69.0 | 68.2 | 5 0 | 40.3 | 40.5 | 40.4 |

## THE INFLUENCE OF TEMPERATURE ON THE SEPARATION OF WHEY FROM CURD.

The next effort was to determine how great is the effect of heat upon the process of removing moisture from curd by using different temperatures in the four vats and observing the moisture content of each curd at intervals. In a similar way various elements of the process other than temperature were studied. Each part of the work was repeated several times. The data, which are recorded herein, are representative in every case of several concordant experiments and are believed to be indicative of the effects which would be produced in any vat, large or small, under the conditions described.

### THE USE OF FIXED TEMPERATURES FOR SETTING AND FIRMING.

In the experiment described below the milk contained 4 per cent fat, and was set with 4 ounces of rennet per 1,000 pounds at 86°, 92°, 98°, and 104°, respectively, in the four different vats. These temperatures were maintained until the whey was drawn, after which the curds were slowly warmed or cooled, as required, to bring them all to 86° when hooped. The milk began to thicken in twelve, ten, nine, and nine minutes, respectively, and the curds were cut into one-half-inch cubes in thirty, thirty, twenty-three, and twenty-three minutes after adding rennet. Care was exercised to have the cubes of uniform size, to maintain the different vats at the prescribed temperatures, and to handle them alike in all other respects. The curds were not stirred on the rack. The acidity of the milk in each vat was 0.17 per cent when set, and of the whey 0.155 per cent when drawn. The moisture content is given in Table 4. (See also fig. 3.)

TABLE 4. —*Moisture content of curds held at fixed temperatures from setting to dipping.*

| Time after cutting. | Operation. | Moisture in curd. | | | |
|---|---|---|---|---|---|
| | | Vat I. Temperature 86°. | Vat II. Temperature 92°. | Vat III. Temperature 98°. | Vat IV. Temperature 104°. |
| *Hrs. m.* | | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 0 | Cut | 87.0 | 87.0 | 87.0 | 87.0 |
| 0 30 | | 83.1 | 81.6 | 78.6 | 77.3 |
| 1 30 | | 77.8 | 75.3 | 71.9 | 69.4 |
| 2 30 | Dipped | 73.0 | 69.8 | 65.4 | 64.0 |
| 2 45 | | 64.3 | 62.7 | 57.5 | 55.4 |
| 3 0 | | 60.5 | 56.0 | 52.3 | 52.0 |
| 4 0 | Milled | 53.9 | 49.7 | 47.0 | 45.5 |
| 6 0 | Salted | 43.4 | 43.3 | 41.4 | 41.6 |
| 6 20 | Hooped | 39.8 | 40.1 | 39.2 | 39.0 |

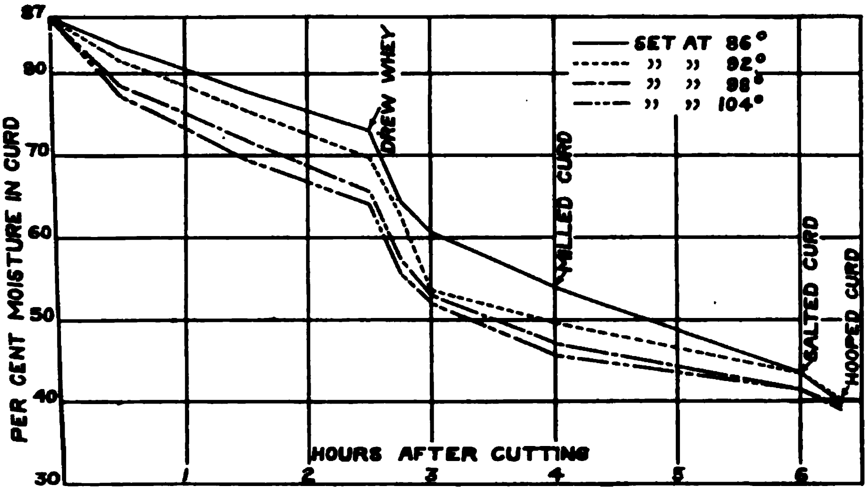

FIG. 3.—Effect of different temperatures at setting. Four vats were held at 86, 92, 98, and 104° from setting until the whey was drawn. It will be seen that the 98 and 104° curves lie close together.

The figures show that the temperature is a very important factor in the removal of moisture from cheese curds. Some 18 degrees difference in temperature made 9 per cent difference in moisture content when dipped. The fact that in this experiment the four curds, set and firmed at 86°, 92°, 98°, and 104°, respectively, had the same moisture content when hooped, shows that this is not wholly dependent on the moisture content when the whey is drawn, but is influenced by other important factors during the later stages of the process, which will be referred to again.

## THE USE OF DIFFERENT TEMPERATURES FOR SETTING THE MILK.

In factory practice vats of milk are usually set at about 86° F. and later heated to a temperature in the neighborhood of 100°. When it is desirable, as with overripe milk, to shorten the time and to get the milk coagulated quickly, so as to cut and heat the curd as soon as possible, five or ten minutes may be saved by setting the vat as high as 96°, as suggested by J. W. Robertson,[a] though the loss of fat is slightly greater. However, since overripe milk thickens faster than sweet milk with rennet at 86°, many makers never use a higher temperature for setting than 86° at any time.

In the following experiment four vats of mixed milk of 0.20 per cent acidity were heated to 86°, 92°, 98°, and 104°, respectively, and set with 3 ounces of rennet. Each was cut in twenty-two minutes. Heat was turned on fifteen minutes after cutting, and the temperature was 104° in each vat thirty-five minutes after cutting. The acidity of the whey increased alike in the four vats, and this, with the moisture content of the curds, is shown in Table 5. (See also fig. 4.)

TABLE 5.—*Moisture content of curds from overripe milk set at 86°, 92°, 98°, and 104°, and heated to 104°.*

| Time after cutting. | | Acidity of whey. | Moisture content of curd. | | | |
|---|---|---|---|---|---|---|
| | | | Vat I, set at 86°. | Vat II, set at 92°. | Vat III, set at 98°. | Vat IV, set at 104°. |
| *Hrs.* | *m.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 | 0 | 0.135 | ........ | ........ | ........ | ........ |
| 0 | 35 | ........ | 77.7 | 76.3 | 74.9 | 73.0 |
| 1 | 0 | .157 | 69.4 | 69.5 | 68.6 | 69.9 |
| 1 | 30 | .18 | 65.6 | 63.5 | 62.4 | 65.5 |
| 2 | 0 | .19 | 60.6 | 58.9 | 58.3 | 60.2 |
| 2 | 30 | .25 | 56.1 | 56.1 | 55.7 | 59.0 |

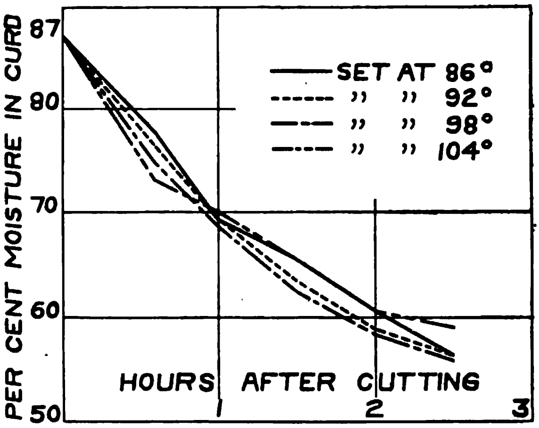

FIG. 4.—Effect of setting curds at different temperatures and heating to the same temperature after cutting. The curds differed widely in moisture content one-half hour after cutting, but were closely alike one hour after cutting.

The use of higher temperatures of setting induces more rapid separation of whey at first. When the curd is heated to 104° the moisture separates more rapidly at first but later at a decreased rate, so that within one hour after setting the moisture content is the same in curds I, II, and III. Curd IV, set at the highest temperature, shows the decrease in rate more markedly than the others and contains more moisture than curd III as early as one hour after cutting.

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[a] Monrad, J. H. A. B. C. in cheese making. Springfield, Ill., 1885. P. 29.

The practical application of these facts is as follows: With milk of this ripeness the whey would probably be drawn when the acidity was 0.18 per cent, one and one-half hours after cutting. Under these conditions a curd set at 98° will be the driest, and the others will contain more moisture in order, as set at 92°, 86°, and 104°. With milk of such high acidity handled in this manner the use of 104° does not get the curd any drier than 86°, nor as dry as 92° or 98°.

A possible explanation for these facts may be that a very rapid initial rate of removal of moisture (to less than 74 per cent in vat IV in one-half hour after cutting) may separate moisture from the surface layer of curd faster than the moisture can move from the center to the surface, thus forming a relatively dry and impervious layer of curd at the surface through which the remaining moisture passes more slowly.

Another experiment was performed in a similar manner with milk of lower acidity, and is described here for convenient comparison with the preceding.

Mixed milk of 0.16 per cent acidity and 4 per cent fat content was placed in four vats, which were heated to 86°, 92°, 98°, and 104°, respectively, and set with 4 ounces of rennet per 1,000 pounds of milk, but without the addition of any starter. The acidity of the whey rose slowly and reached 0.16 per cent two and one-half hours after the curds were cut, at which time the whey was drawn. Each curd was cut twenty-six minutes after adding rennet, heated fifteen minutes later, and reached 104° thirty-five minutes after cutting. The moisture content of the four curds is shown in Table 6 and figure 5.

TABLE 6.—*Moisture content of curds set at 86°, 92°, 98°, and 104° and firmed at 104°.*

| Time after cutting. | | Moisture in curd. | | | |
|---|---|---|---|---|---|
| | | Vat I, set at 86°. | Vat II, set at 92°. | Vat III, set at 98°. | Vat IV, set at 104°. |
| *Hrs.* | *m.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 | 0 | 87.0 | 87.0 | 87.0 | 87.0 |
| 0 | 30 | 81.6 | 80.3 | 77.7 | 75.7 |
| 1 | 0 | 72.2 | 71.9 | 71.7 | 71.0 |
| 1 | 30 | 67.6 | 68.0 | 69.3 | 68.4 |
| 2 | 30 | 62.7 | 62.9 | 62.0 | 62.8 |

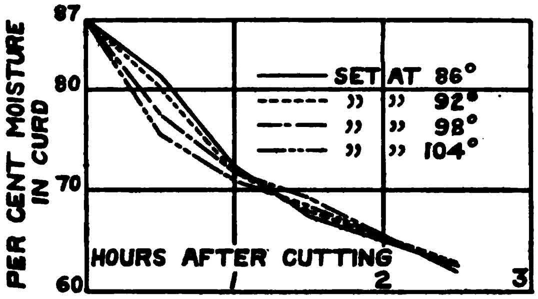

FIG. 5.—Effect of conditions same as in figure 4, but with milk not so ripe. Note the wide variation at first and the close agreement after one hour.

In this case, where the milk was sweeter, the initial rate of removal of moisture was less than in the experiment preceding. Curd IV contained more than 75 per cent of moisture one-half hour after cutting. Under these conditions the vats set highest lost moisture more quickly at first and more slowly after one-half hour, so that they all had practically the same moisture content one, one and one-half, and two and one-half hours after cutting. There is therefore no advantage in using a higher temperature than 86° in such a case. With milk that is not overripe 86° is commonly employed for setting the vat for several reasons—it is high enough to permit ripening of the milk, it insures a reasonably rapid rate of coagulation with rennet, the loss of fat is low, and the curd can be freed from moisture quite as thoroughly on raising the temperature after cutting as it could be if a higher temperature had been used for setting the vat.

## HEATING THE CURD AFTER CUTTING.

While milk is quite generally set at 86° in Cheddar cheese factories, the practice varies as to the temperature used in "cooking" the curds after cutting. Many makers ordinarily use 98°, others 100° or 102°, a smaller number use 104°, and a few, though it is difficult to say how many, heat the curd as high as 106°, 110°, or 114° in the whey.

To determine the influence of different temperatures on the rate of moisture separation, four vats of milk, containing 4.2 per cent fat and 0.182 per cent acid were set at 86° with 3 ounces of rennet per 1,000 pounds. All were cut alike thirty-five minutes later, and fifteen minutes after cutting steam was turned on three of them. In thirty-five minutes after cutting the four vats were at 86°, 98°, 104° and 110°, at which temperatures they were held until the whey was drawn. The curds were then slowly warmed or cooled, as required, to bring them to about 86° at the time they were hooped. The whey acidity was 0.185 per cent when drawn. The curds were put on the rack and matted without stirring. The drainings from the rack after milling contained 18, 14, 14, and 34 grams of fat, respectively, the temperatures of the curds when milled being 88°, 94°, 100°, and 102°. The moisture content is shown in Table 7. (See also fig. 6.)

TABLE 7.—*Moisture in curds cooked at 86°, 98°, 104°, and 110°.*

| Time after cutting. | Operation. | Moisture in curd. | | | |
|---|---|---|---|---|---|
| | | Vat I, cooked at 86°. | Vat II, cooked at 98°. | Vat III, cooked at 104°. | Vat IV, cooked at 110°. |
| *Hrs. m.* | | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 0 | .................... | 87.0 | 87.0 | 87.0 | 87.0 |
| 0 30 | .................... | 82.2 | 80.1 | 80.2 | 81.0 |
| 1 30 | .................... | 76.3 | 69.3 | 67.3 | 62.9 |
| 2 30 | Drawn............ | 73.6 | 63.7 | 62.0 | 57.9 |
| 3 0 | .................... | 58.0 | 50.0 | 46.2 | 43.6 |
| 4 0 | Milled............ | 52.0 | 44.0 | 41.9 | 41.6 |
| 6 20 | Hooped........... | 40.4 | 37.3 | 35.6 | 34.3 |

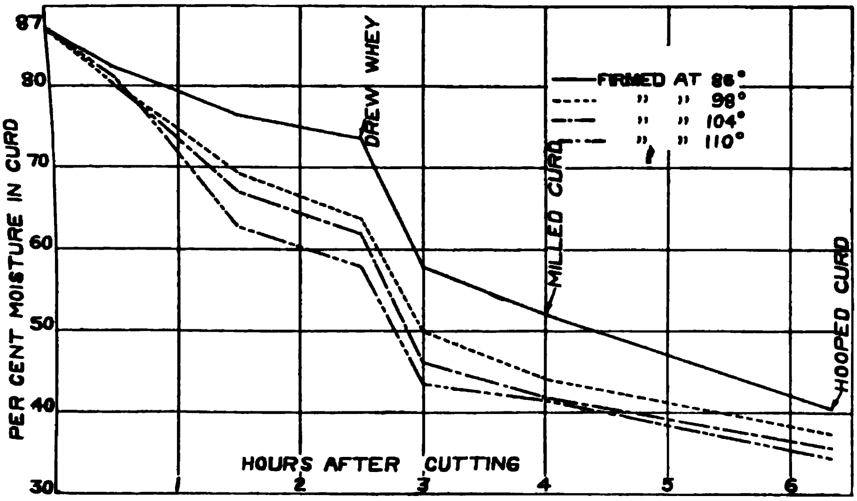

FIG. 6.—Effect of setting the milk at the same temperature and heating to different temperatures. Four vats were set at 86°, but firmed at 86, 98, 104, and 110°. Note the small differences between the 98 and 104° curves, as is also shown by figure 3.

The temperature to which the vat is heated after cutting has a very marked influence on the rate of removal of moisture while the curd is in the whey. The higher the temperature the more rapid the separation of whey under the conditions described.

### TIME AND RATE OF HEATING THE VAT AFTER CUTTING.

With respect to the time of beginning to heat the vat after cutting, and the rate at which it should be heated, Monrad[a] quotes the following directions from Robertson's "Pointers for Cheese Factories:"

> The application of heat should be delayed for fifteen minutes after stirring is commenced. The temperature should be gradually raised to 98° F. at a rate not faster than 1° every four or five minutes. In the case of a quick curd these rules may be disregarded.

On the same subject Decker[b] says:

> Curd being a poor conductor of heat, a rise of 1° in five minutes is fast enough to heat normal working milk. If it is heated too fast it will cook the particles on the outside and retain the whey inside of the curd.

Van Slyke and Publow[c] give the following directions:

> Care must always be taken not to raise the temperature of the curd too rapidly. Usually the temperature can be raised 2° in every five minutes, but when the lactic acid formation is slow 1° every five minutes may be sufficient. If after cutting the whey around the curd shows 0.12 per cent acidity, allow sixty minutes for heating; if 0.15 per cent acidity, allow twenty minutes for heating. Applying heat too fast hardens the outside of the curd and prevents the escape of the whey.

The practice of beginning to heat the vat very soon after cutting the curd, and raising the temperature rapidly, is followed almost solely when the milk is overripe. Some cheese makers intentionally ripen milk to 0.20 per cent acidity or more and habitually apply heat in this manner. Experiments were undertaken to determine whether by such treatment the moisture content is reduced more rapidly than by the usual slower method of heating.

In one experiment milk of 0.20 per cent acidity in four vats was set with 4 ounces of rennet and cut with ½-inch knives in twenty-five minutes. The first and second vats were heated to 104° and the third and fourth vats to 110°. The first and third vats were stirred fifteen minutes and were heated in twenty minutes; the second and fourth were stirred six minutes before heating and were heated in seven minutes. The acidity of the whey when drawn was 0.215 per cent. The time of each operation and the moisture content of the resulting curds are shown in Table 8. The curds were not stirred on the rack. The comparative effect of rapid and slow heating is illustrated in figure 7.

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[a] Loc. cit., p. 30.
[b] Loc. cit., p. 60.
[c] Loc. cit., pp. 30–31.

TABLE 8.—*Moisture in curds heated slowly and rapidly to 104° and 110°.*

| Time after cutting. | Operation. | Moisture in curd. | | | |
|---|---|---|---|---|---|
| | | Vat I (heating begun at 15 minutes and reached 104° at 35 minutes). | Vat II (heating begun at 6 minutes and reached 104° at 11 minutes). | Vat III (heating begun at 15 minutes and reached 110° at 35 minutes). | Vat IV (heating begun at 6 minutes and reached 110° at 11 minutes). |
| *Hrs. m.* | | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 0 | ........... | 87.0 | 87.0 | 87.0 | 87.0 |
| 0 30 | ........... | 76.2 | 73.9 | 77.6 | 73.2 |
| 1 0 | ........... | 65.5 | 67.3 | 64.7 | 65.2 |
| 1 30 | ........... | 61.5 | 64.7 | 60.2 | 61.5 |
| 2 30 | Drawn ... | 53.2 | 59.0 | 55.5 | 58.4 |
| 3 0 | ........... | 45.0 | 47.2 | 45.6 | 46.3 |
| 4 0 | Milled..... | 41.7 | 42.5 | 40.4 | 41.9 |
| 6 0 | Salted..... | 39.9 | 39.6 | 37.2 | 37.2 |
| 6 20 | Hooped... | 37.8 | 37.0 | 33.9 | 33.2 |
| Whey fat (per cent).. | | 0.175 | 0.20 | 0.22 | 0.25 |
| Yield of green cheese per 100 pounds milk (pounds)........... | | 9.5 | 9.32 | 9.07 | 8.8 |

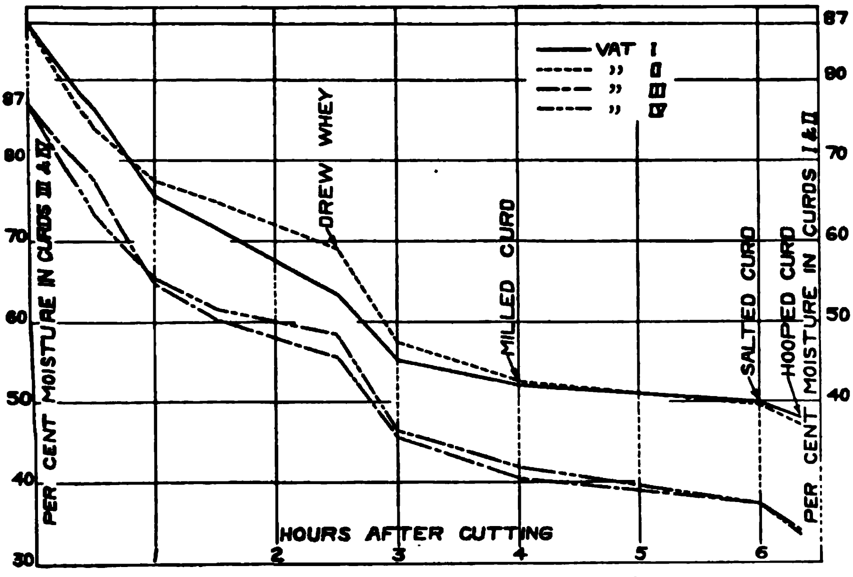

FIG. 7.—Effect of rapid and slow heating. Two vats (I and III) were heated slowly to 104 and 110°, respectively. Two other vats (II and IV) were heated rapidly to the same temperatures. Note that the curves cross at about one hour after cutting. The two pairs of curves are separated so as to be more readily traced.

The results obtained at 110° and 104° show that at both temperatures early and rapid heating caused more rapid separation of whey during part of the first hour, but after the first hour the separation of moisture was slower than when the ordinary method of heating was used. The rapidly heated curds contained as much or more moisture two and one-half hours after cutting than did the more slowly heated curds. In other similar experiments the same general results were obtained.

There is a greater loss of fat in the whey and a smaller yield of cheese from each of the more rapidly heated vats, instead of a larger yield. These facts are of importance to those cheese makers who habitually ripen milk to a high percentage of acidity and heat the curd as rapidly as possible after cutting, with the object of obtaining a larger yield, due to water being retained within the toughened walls of the cubes. The fact is that these walls break under the pressure as soon as the curd is piled up to mat, and the liquid contents escape, partly at this stage and partly after milling, in the form of white whey of high fat content. As a result the yield of cheese is less, instead of more, than that obtained when the skin-and-pulp condition of curd is avoided.

It was observed that in vats II and IV, which were heated rapidly, the surface of the cubes became tough, while the interior remained soft and pulpy, the cubes thus losing homogeneity, which did not occur in vats I and III. The moisture content of the two 110° curds was about 4 per cent lower than that of the two 104° curds when hooped.

Another experiment was carried out in which sweeter milk was used than in the last, as follows: Four vats of fresh mixed milk of 4 per cent fat content and 0.162 per cent acidity were set at 86°, with 4 ounces of rennet per 1,000 pounds. Each was cut thirty minutes later. The time and rate of heating were varied and are indicated in Table 9, together with the moisture content of the curds. The acidity of the whey was 0.112 per cent when the curd was cut and 0.132 per cent two and one-half hours later when the curd was dipped. The results show that the different methods of heating had a marked effect on the moisture content early in the process, but owing to lack of acidity the curds all practically stopped firming when the moisture content reached about 65 per cent. The differences in moisture content, so marked at first, were thus lost. The difference in behavior between curds from ripe milk and from sweet milk will be referred to again in the discussion of acidity. The results of this experiment are shown in figure 8.

**TABLE 9.**—*Influence of rapid and early heating on the moisture content of curds from sweet milk.*

| Time after cutting. | Vat I (began to heat at 15 minutes and reached 104° at 35 minutes). | Vat II (began to heat at 15 minutes and reached 104° at 25 minutes). | Vat III (began to heat at 30 minutes and reached 104° at 35 minutes). | Vat IV (began to heat at 5 minutes and reached 104° at 10 minutes). |
|---|---|---|---|---|
| *Hrs. m.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 0 | 87.0 | 87.0 | 87.0 | 87.0 |
| 0 30 | 80.5 | 78.1 | 83.0 | 74.3 |
| 1 0 | 73.8 | 71.9 | 72.5 | 68.0 |
| 1 30 | 68.8 | 68.0 | 68.4 | 66.9 |
| 2 0 | 66.7 | 66.2 | 65.7 | ............ |
| 2 30 | 65.2 | 64.4 | 64.6 | 64.6 |

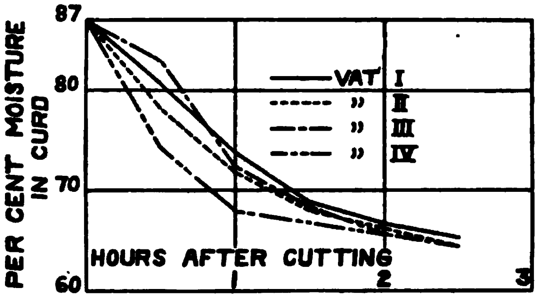

FIG. 8.—Effect of heating curd rapidly after cutting. The curds which were heated most quickly to 104° after cutting lost moisture most rapidly at first, but in two hours after cutting these differences had disappeared.

## INFLUENCE OF SIZE OF CUBES ON MOISTURE IN CURD.

It is generally believed that the smaller the cubes into which a curd is cut the more rapid will be the separation of whey; also that when a curd is cut into pieces of irregular size the smallest ones become firm first. To show definitely what differences of moisture content are produced by using different sized knives the following experiment will be described.

Four vats of milk, acidity 0.20 per cent, were set with 3 ounces of rennet at 86° and each was cut twenty-five minutes later. The curds were cut with different-sized knives, but in all other respects were handled exactly alike. They were not stirred on the racks, and were hooped at 86°. The whey acidity was 0.225 per cent two and one-half hours after cutting the curd. (See Table 10 and fig. 9.)

TABLE 10.—*Moisture content of curds cut with different-sized knives.*

| Time after cutting. | Operation. | Moisture in curd. | | | |
|---|---|---|---|---|---|
| | | Vat I, cut with $\frac{1}{4}$-inch knives. | Vat II, cut with $\frac{3}{8}$-inch knives. | Vat III, cut with $\frac{1}{2}$-inch knives. | Vat IV, cut with $\frac{3}{4}$-inch knives. |
| *Hrs. m.* | | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 0 | ............ | 87.0 | 87.0 | 87.0 | 87.0 |
| 0 30 | ............ | 75.5 | 77.0 | 79.7 | 85.6 |
| 1 30 | ............ | 56.5 | 61.3 | 65.6 | 76.5 |
| 2 30 | Dipped... | 49.7 | 52.9 | 58.2 | 69.8 |
| 3 0 | Milled..... | 39.5 | 43.1 | 46.3 | 49.8 |
| 6 0 | Salted..... | 38.2 | 41.0 | 42.7 | 46.6 |
| 6 20 | Hooped... | 33.9 | 35.6 | 35.6 | 38.3 |

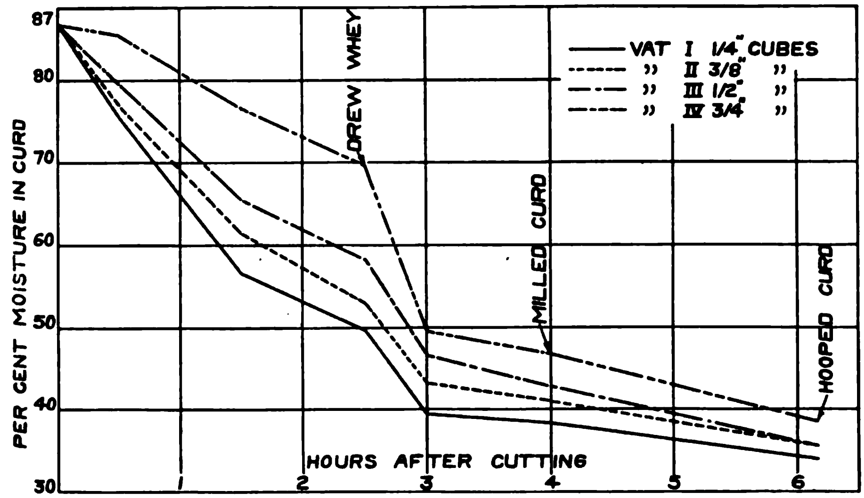

FIG. 9.—Effect of cutting the curd with different-sized curd knives. Note especially the curves for vats II and III.

The difference in moisture content between the curds was much greater just before drawing the whey than when the curds were hooped. The moisture content of the ⅜-inch cubes reached 58 per cent about forty-five minutes earlier than the ½-inch cubes. A pair of ⅜-inch knives might well be included in every factory outfit. The advantages of using the ⅜-inch knives instead of cutting the curd many times with the usual ½-inch knives are quicker cutting, more uniform size of cubes in the vat, and more uniform size of cubes on successive days. The ⅜-inch and ¼-inch curd knives used in this experiment were made with staggered blades, as shown in figure 10, so that the compression which the curd undergoes in passing between the blades is decreased. There is no difficulty in cutting the curd into cubes of uniform size with knives constructed in this manner.

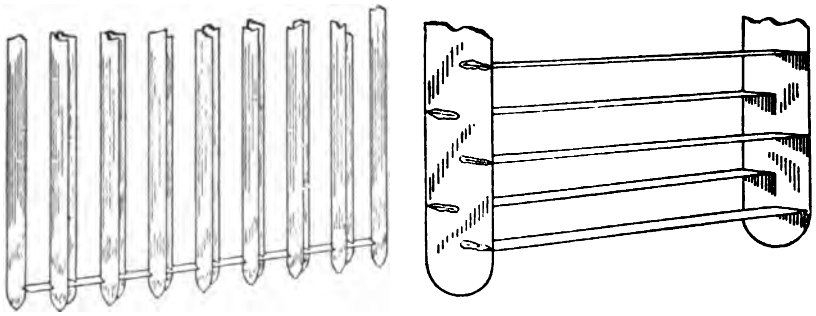

FIG. 10.—Two curd knives with staggered blades which were used to allow the curd to pass through with less compression than if the blades were all in the same plane.

The difference in rate of moisture separation, where the different-sized knives were used, is no doubt related to the fact that the surface area of all the cubes cut from a curd is inversely proportional to the distance between the blades of the knife used. The smaller the cube, the less is the distance which moisture travels in passing from center to surface of the cube.

TABLE 11.—*Number and dimensions of cubes cut with different-sized knives.*

| Distance between blades of knives. | Number of cubes per cubic foot. | Solid contents of cube. | Area of surface of cube. | Surface area of all cubes per cubic foot. |
|---|---|---|---|---|
| *Inch.* | | *Cu. in.* | *Sq. in.* | *Sq. in.* |
| Three-fourths........ | 4,096 | 0.422 | 3.375 | 13,824 |
| One-half.......... ..... | 13,824 | .125 | 1.50 | 20,736 |
| Three-eighths........ | 32,768 | .053 | .844 | 27,656 |
| One-fourth .......... | 110,592 | .0156 | .375 | 41,472 |

## EFFECT OF RENNET UPON SEPARATION OF MOISTURE FROM CURD.

It is sometimes supposed that variations in the proportion of rennet, within reasonable limits, influence the rate at which moisture is expelled from curd. Quoting from J. W. Robertson's "Pointers for Cheese Factories," Monrad[a] says:

> The more rennet there is used the more moisture will be retained in the cheese under similar conditions. When milk is overripe or acidy a proportionately increased quantity of rennet should be used to effect a sufficient separation of the moisture from the curd (often termed "cooking") before the presence of lactic acid is perceptible to the taste or smell or is discernible by the hot-iron test.

Scherer[b] says:

> The stronger the action of the rennet and the sooner the casein is thrown down the more powerful the contraction of the curd and the larger the volume of whey expressed. This means a reduction in the residual water in the curd and an increase in its final dryness and firmness.

H. H. Dean[c] says:

> It is thought by some that a large quantity of rennet produces a cheese with a great deal of moisture. This is not so, but rather the reverse. The length of time from setting to dipping and from dipping to salting the curd does not seem to be affected by the quantity of rennet used in the milk.

F. J. Lloyd,[d] who studied factory conditions in England, writes:

> If an excess of rennet be employed, then when the scald is applied the curd is drawn together too rapidly and the whey is expressed before it has had time to per-

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[a] Loc. cit., p. 29.

[b] Scherer, Robert. Casein: Its preparation and technical utilization. Translated from the German by Charles Salter. New York, 1906. P. 7.

[c] Dean, Henry H., Canadian dairying. Toronto, 1903. P. 162.

[d] Lloyd, F. J. Report on investigations in Cheddar cheese making, 1891-98. London, 1899. P. 104.

**form its proper function, namely, to enable the bacteria feeding on it to bring about the desired acidity within the curd. An excess of rennet, by contracting the curd with too much force, may also cause some of the fat to be pressed out of it and lost in the whey.**

As these quotations indicate, the ideas prevalent at present on this subject are based largely on conjecture.

It is well known that when more rennet is used the milk thickens quicker and the curd is ready to cut sooner and is less fragile after cutting, but whether the curd after cutting gives up whey any faster is a question yet to be answered.

In the following experiment four vats were set with 2, 3, 4, and 6 ounces of rennet per 1,000 pounds, respectively, and were cut forty minutes later. The moisture content of the curds at different stages are indicated in Table 12 and figure 11.

TABLE 12.—*Influence of quantity of rennet on the separation of whey.*

| Time after cutting. | | Operation. | Moisture in curd. | | | |
|---|---|---|---|---|---|---|
| | | | Vat I, rennet 6 ounces. | Vat II, rennet 4 ounces. | Vat III, rennet 3 ounces. | Vat IV, rennet 2 ounces. |
| *Hrs.* | *m.* | | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 | 0 | ............ | 87.0 | 87.0 | 87.0 | 87.0 |
| 0 | 30 | ............ | 81.0 | 81.0 | 79.1 | 78.2 |
| 1 | 10 | ............ | 66.8 | 66.8 | 67.7 | 65.6 |
| 1 | 50 | ............ | 63.0 | 61.0 | 62.9 | 60.7 |
| 2 | 30 | Dipped... | 58.2 | 55.2 | 56.5 | 56.3 |
| 3 | 0 | ............ | 45.4 | 46.0 | 46.2 | 45.8 |
| 4 | 0 | Milled .... | 42.0 | 42.3 | 42.0 | 42.5 |
| 5 | 0 | Salted..... | 41.0 | 40.7 | 40.9 | 41.0 |
| 5 | 30 | Hooped... | 37.8 | 37.5 | 37.8 | 37.8 |

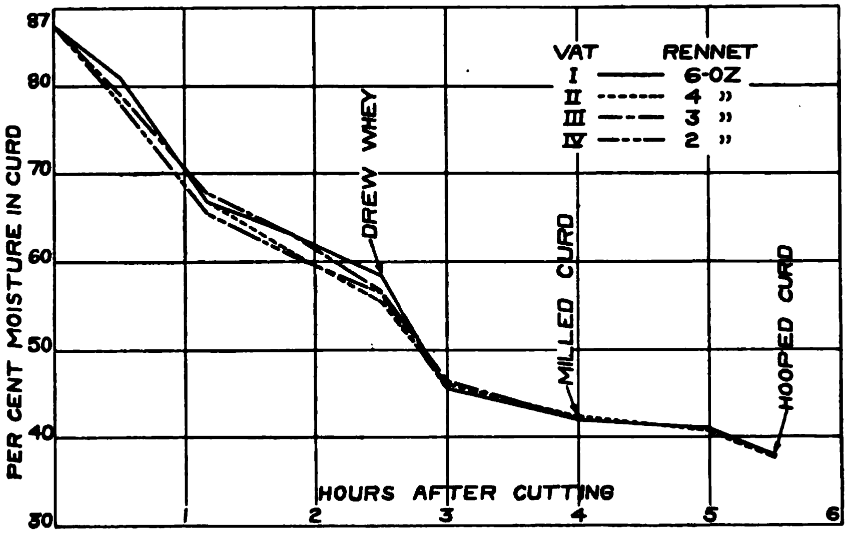

FIG. 11.—Effect of the use of different amounts of rennet. The differences in these curves are no greater than those in figure 1, due to experimental error. It will be seen that the use of different amounts of rennet did not affect the rate of separation of whey after cutting.

The moisture content of these four curds did not differ widely at any time. The variations are no greater than the unavoidable variations due to errors in cutting, sampling, etc., shown in Table 2 and figure 1. The curd with least rennet appears to have lost moisture a very little faster at first than the others, which slight difference, if it did occur, may have been due to slightly greater fragility of the low-rennet curd.

The conclusion from these and other similar experiments is that the rate at which curds lose moisture after cutting is not affected by variations in the proportions of rennet extract between 2 and 6 ounces per 1,000 pounds of milk.

The cheese maker saves time by using more rennet, for the reason that the curd gets thick enough to cut more quickly, and can be stirred and heated a little sooner after cutting. When a small proportion of rennet is used a more fragile curd may be obtained, and this may be more extensively broken into smaller pieces during the stirring process, and the separation of moisture thereby hastened. But this effect, if it occurs, is directly due to the size of the pieces of curd and only indirectly to the proportion of rennet.

### LENGTH OF TIME FROM SETTING TO CUTTING.

Monrad[a] quotes Robertson as follows:

> The results of late investigations recommend that the curd be allowed to become fairly firm before it is cut, except in the case of a quick-working curd. More moisture is retained in the cheese and a better yield is thus obtained.

Van Slyke and Publow,[b] writing on the control of moisture in cheese making, say:

> When the curd is cut before it becomes hard, the whey escapes more easily than in the case of curd cut after it becomes hard. * * * Among the most common causes of excessive water in curd and cheese are the following: (1) Cutting curd coarse or when too hard. * * *

Since increase in the proportion of rennet does not affect the rate at which moisture separates from a curd, it might be expected that the length of time the rennet is allowed to act before the cutting of the curd would not influence the rate of moisture separation. That this is true was shown by several experiments, one of which is described below.

Two vats of milk of 0.165 per cent acidity were heated to 86° at the same time and rennet extract added at once to one at the rate of 4 ounces per 1,000 pounds. Both vats were held at 86° and rennet was added to the second vat sixty minutes later. The milk had visibly thickened twelve minutes later. As the vats were kept warm for the same length of time, the acidity of the milk or whey was alike in the two. In vats I and II, respectively, the curds were cut one hour and twenty-six minutes, and thirty-two minutes after adding rennet. The acidity of whey in each was 0.125 per cent when cut and 0.18 per cent two and one-half hours later, when drawn. The moisture content of the curd is shown in Table 13. (See also fig. 12.)

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[a] Loc. cit., p. 49.

[b] Loc. cit., pp. 46-49.

TABLE 13.—*Moisture of curds cut, respectively, eighty-six minutes and thirty-two minutes after adding rennet.*

| Time after cutting. | Operation. | Moisture in curd. | |
|---|---|---|---|
| | | Vat I, cut 86 minutes after adding rennet. | Vat II, cut 32 minutes after adding rennet. |
| *Hrs. m.* | | *Per cent.* | *Per cent.* |
| 0 0 | ............ | 87.0 | 87.0 |
| 0 30 | ............ | 79.25 | 78.8 |
| 1 30 | ............ | 66.9 | 66.8 |
| 2 30 | Dipped... | 59.2 | 60.8 |
| 3 0 | ............ | 45.2 | 44.8 |
| 4 0 | Milled..... | 42.5 | 42.7 |
| 5 0 | Salted..... | 39.9 | 40.4 |
| 5 20 | Hooped... | 38.3 | 38.3 |

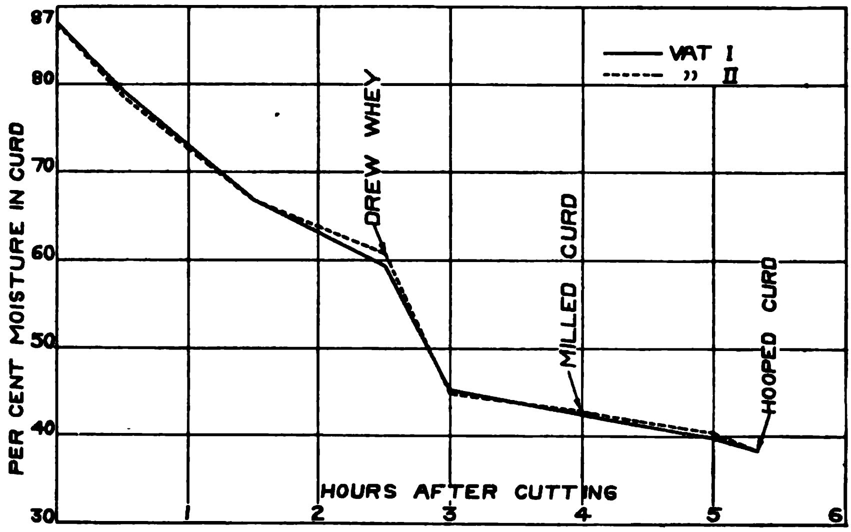

FIG. 12.—Effect of different periods of action by the rennet. It will be seen that the length of time the rennet acted on the curd from setting to cutting does not affect the rate at which the moisture separates after cutting.

From these experiments it is concluded that the rate of separation of moisture is not directly affected by the action of rennet for periods differing by one hour previous to cutting. If the curd develops more acid as a result of standing longer before cutting, any observed difference in the rate of whey separation may be due to the increased acidity but not to more prolonged action of rennet before cutting. If a curd is cut so early that it is very fragile and breaks up badly, any increased rate of firming must be ascribed directly to the decreased size of the particles of curd and not to the period of time from setting to cutting.

In another experiment 1,000 pounds of milk was pasteurized at 160° to 165° in a continuous pasteurizer of the disk type. The milk was then collected in one large vat, thoroughly mixed, and four 200-pound portions were placed in the experimental vats. The acidity was 0.16 per cent after pasteurizing, and in order to make the milk coagulate easily with rennet the acidity was raised to 0.20 per cent by adding 453 c. c. of dilute hydrochloric acid to each vat. One vat was set with rennet at the rate of 2 ounces and the other three vats at the rate of one-fourth ounce. The three latter vats were cut three, four, and five hours, respectively, after adding rennet. The milk was pasteurized to prevent ripening during these periods. The curds were handled in a uniform manner in all respects, unless otherwise stated. The time of the various operations and the moisture content of each curd is shown in Table 14.

TABLE 14.—*Effect of varying the proportion of rennet and the time from setting to cutting upon the rate of moisture separation.*

| Time after cutting. | | Moisture in curd. | | | |
|---|---|---|---|---|---|
| | | Vat I, ¼ ounce rennet; curd cut in 5 hours. | Vat II, ¼ ounce rennet; curd cut in 4 hours. | Vat III, ¼ ounce rennet; curd cut in 3 hours. | Vat IV, 2 ounces rennet; curd cut in 40 minutes. |
| *Hrs.* | *m.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 | 0 | 87.0 | 87.0 | 87.0 | 87.0 |
| 0 | 30 | 80.8 | 80.4 | 80.7 | 81.4 |
| 1 | 0 | 74.3 | 74.4 | 73.1 | 73.0 |
| 1 | 30 | 71.1 | 70.7 | 70.7 | 71.4 |
| 2 | 0 | 68.1 | 68.5 | 67.9 | 67.3 |
| 2 | 30 | 67.4 | 67.0 | 67.0 | 66.2 |

The figures are practically identical for the four vats, showing that where acidity does not rise by ripening, the rate of moisture separation is not affected by variations in the time from setting to cutting, nor in the proportion of rennet used.

## INFLUENCE OF ACIDITY ON MOISTURE OF CURD IN VAT.

In discussing this topic it is necessary to consider the sources of acidity and the accuracy with which the acid content of a curd can be determined by the methods in common use.

### FORMATION OF ACID WITHIN THE CURD.

Acidity is commonly developed in milk for cheese making by bacterial ripening. Since most of the bacteria present in milk remain in the curd[a] during the separation of whey, it follows that the principal seat of acid formation in the cheese vat is in the curd. This fact may be demonstrated by two simple experiments, as follows:

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[a] L. D. Bushnell, bacteriologist, formerly in the employ of the Dairy Division, found that 95 to 98 per cent of the bacteria present in milk are retained in the curd after the latter has been cut into cubes.

1. Soon after cutting the curd take a pint of the whey from the vat and place it in a small tin bucket. Hang this in the vat so as to keep it at the same temperature as the vat. Determine the acidity of the whey in the bucket and that in the vat at thirty-minute intervals. After the portion of whey is removed from contact with the curd its acidity remains practically constant for several hours, while the acidity of the whey in the vat increases steadily, showing that increased acidity of whey is a result of contact with curd and transfer of acid therefrom.

2. Place a portion of curd with some whey in a bucket soon after cutting and keep it warm, as before. Pour the whey out of the bucket as fast as it separates from the curd, leaving only enough whey to keep the curd covered, and stir to prevent matting. Determine acidity of whey in bucket and vat at intervals. In the bucket, where the proportion of whey to curd is smaller than in the vat, the acidity of the whey rises more rapidly than in the vat. This is because the acid coming out of the curd in the bucket is diluted with a smaller proportion of whey than is the case in the vat, and it shows that the rate at which the acidity of whey rises depends on the proportion of curd in contact with it, and that therefore the curd is the principal source of acid.

## DETERMINATION OF ACIDITY WITHIN THE CURD.

As ripening progresses, the concentration of acid within the curd rises higher than in the surrounding whey on account of the bacterial activity in the curd. This is shown by the following experiment:

To 1,000 pounds of milk of 0.16 per cent acidity was added 1 pound of starter, and after ripening for one hour at 86° the vat was set with 4 ounces of rennet per 1,000 pounds, and cut thirty minutes later. Heat was applied fifteen minutes after cutting, and the temperature reached 100° fifteen minutes later. The whey above the curd was titrated at frequent intervals, the vat being stirred well before sampling. The ratio of acid to moisture within the curd—that is, the concentration of the acid solution within the curd—was also determined by taking representative samples of the curd, removing adhering moisture by the use of filter paper, and making determinations of moisture and of acid therein.

Two 10-gram portions of each sample were used for moisture determination in the usual manner. Two 10-gram portions were at once placed in two clean porcelain mortars, rubbed with clean quartz sand and water, filtered on absorbent cotton, and washed by decantation in the mortar (the sand may be omitted). In previous work it has been found that the curd, ground in cold water, made a very sticky emulsion, which could not be filtered on paper or cotton, but by th addition of warm water to the mass of curd and sand the fine parti- cles of curd collected quickly in a loose, friable cake, so that th aqueous solution of lactic acid could be decanted and filtered with n trouble or delay. The cake of curd and sand was then ground wit more water and decanted. Very hot water makes the ground cur form a rubbery mass, which can not be ground up, but water at 60 t 70° C. permits the curd to be washed rapidly and completely.

The filtrate from each 10-gram portion of curd, amounting to 20 c. c., was turbid from fat globules, but contained no suspended cur particles, and was titrated with N/10 caustic alkali, using phenolphthalein.

Knowing the weight of moisture (*a*) in 10 grams of curd and th weight of acid (*b*) extracted from 10 grams of the same, the percentag of lactic acid in the water contained in the curd is calculated by di- viding *b* by *a*. The results thus obtained are given in Table 15 The acidity of the whey within the curd reached 0.62 per cent whe the acidity of whey surrounding the curd was 0.215 per cent. Unde these conditions it is clear that the determination of the acidity o whey, by titration, does not indicate exactly the concentration o acid in the solution within the curd. (See fig. 13.)

TABLE 15.—*Acidity of whey outside and inside of the curd.*

| Time after cutting. | | Acidity of whey outside of curd. | Acidity of whey inside of curd. |
|---|---|---|---|
| *Hrs.* | *m.* | *Per cent.* | *Per cent.* |
| 0 | 30 | 0.115 | 0.154 |
| 0 | 50 | .125 | .178 |
| 1 | 10 | .127 | .215 |
| 1 | 30 | .140 | .257 |
| 2 | 0 | .147 | .295 |
| 2 | 20 | ........... | .359 |
| 2 | 50 | .176 | .442 |
| 3 | 20 | .190 | .48 |
| 3 | 50 | .215 | .62 |
| 4 | 10 | .225 | ........... |

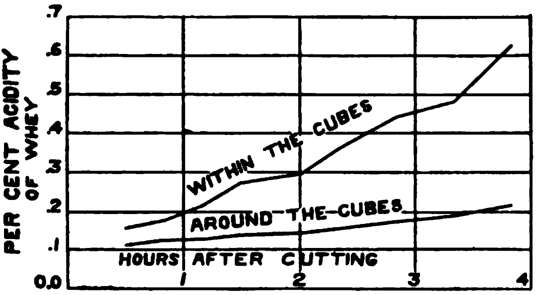

**FIG. 13.**—Showing the proportions of acid within and around the cubes in the vat. The acidity of the whey within the cubes rose to 0.62 per cent, while that of the surrounding whey reached only 0.22 per cent.

## EXPERIMENTS AT CONSTANT AND VARYING ACIDITY.

If milk at any degree of acidity—as 0.25 per cent—is pasteurized before adding rennet, the acidity of the whey in or surrounding the curd does not increase during two or three hours after cutting. While pasteurization has not been widely used in practical cheese making, it is used in experimental work where it is desired to hold milk at a definite acidity for some hours during the cheese-making process. When the acidity of whey does not change during the process of firming it is clear that the concentration of acid within the curd is no greater than in the surrounding whey, and titration of the surrounding whey indicates also the acidity of the whey retained in the curd. By adding to pasteurized milk, either before or after pasteurizing, any desired proportion of hydrochloric or other acid, avoiding coagulation by acid, the acidity of the milk and of the whey, after cutting the rennet curd, may be brought to any figure required for experimental purposes, and held there as long as bacterial action is suppressed. There is thus afforded opportunity for studying the removal of moisture from curd in the following ways:

1. Under conditions of constant acidity, or either high or low concentration, produced either by the action of bacteria or by the addition of acid to the milk.
2. Under conditions of changing acidity as observed in the cheese vat under factory conditions.

It is believed that the study of results obtained under fixed conditions of acidity will enable us to understand more readily the effect of changing conditions of acidity which occur in the factory cheese vat.

## SEPARATION OF MOISTURE FROM CURD AT CONSTANT ACIDITY BY HYDROCHLORIC ACID.

An experiment was made with 1,100 pounds of milk of 0.17 per cent acidity, pasteurized at 150° in the Farrington duplex pasteurizer, and 200-pound portions placed in three vats. The acidity of one of these was raised to 0.25 per cent, calculated as lactic acid, by adding a pound of dilute hydrochloric acid; another vat was raised to 0.20 per cent with acid, and one was kept at 0.17 per cent. All were heated to 86° and set with rennet at the rate of 3 ounces per 1,000 pounds. The curds were cut into ½-inch cubes, and fifteen minutes after cutting heat was applied to each; twenty minutes later all had reached 104°. There was practically no increase in acidity in three hours or more after cutting.

The moisture content and acidity of whey in these vats is shown in Tables 16 and 17, and the effect of acidity on rate of separation of whey from curd is shown in figure 14.

TABLE 16.—*Moisture content of curds of different but fixed acidity.*

| Time after cutting. | Moisture in curd. | | |
|---|---|---|---|
| | Vat I, acidity 0.17 per cent. | Vat II, acidity 0.20 per cent. | Vat III, acidity 0.25 per cent. |
| *Hrs. m.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 0 | 87.0 | 87.0 | 87.0 |
| 0 30 | 82.4 | 81.3 | 79.6 |
| 1 0 | 74.5 | 72.5 | 67.1 |
| 1 30 | 72.2 | 69.0 | 64.2 |
| 2 0 | 70.7 | 67.1 | 62.9 |
| 3 0 | 68.8 | 65.2 | 58.6 |

TABLE 17.—*Acidity of whey in cheese of Table 16.*

| Vat I. | | Vat II. | | Vat III. | |
|---|---|---|---|---|---|
| Time after cutting. | Acidity. | Time after cutting. | Acidity. | Time after cutting. | Acidity. |
| *Hrs. m.* | *Per cent.* | *Hrs. m.* | *Per cent.* | *Hrs. m.* | *Per cent.* |
| 0 0 | 0.11 | 0 0 | 0.13 | 0 0 | 0.17 |
| 2 20 | .12 | 2 20 | .133 | 2 20 | .174 |
| 5 15 | .13 | 3 20 | .138 | 3 20 | .177 |
| ........... | ........... | 4 13 | .142 | 4 10 | .177 |

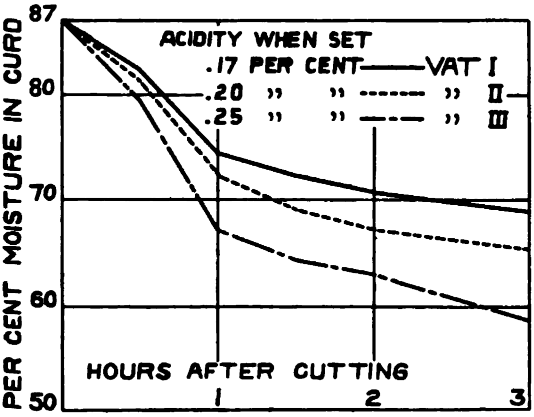

FIG. 14.—Effect of acidity on rate of separation of whey from curd. The milk was acidulated by adding hydrochloric acid. Increasing the acidity accelerated the whey separation.

These and other data show that moisture separates from curd more rapidly when the concentration of acid in solution in the whey within and around the curd is 0.17 per cent than when it is 0.13 or 0.11 per cent, and more rapidly at 0.13 per cent than at 0.11 per cent. Since there was practically no change in the acidity of the whey surrounding the curd, it is certain that the acidity within the curd remained at the observed figures during the period after cutting.

## SEPARATION OF MOISTURE FROM RIPENED MILK CURD AT FIXED ACIDITIES.

In the following experiment the acidity of the milk was raised by ripening, not hydrochloric acid, to 0.177, 0.21, and 0.26 per cent, respectively, in the three vats. The milk was then heated to 150° in the vats by passing steam into the jackets, and cooled by filling the jackets with cold water, stirring all the time. After pasteurizing, each vat was set at 86° with 3 ounces of rennet per 1,000 pounds. The milk became visibly thickened in eleven, seven, and four minutes, respectively, and the curds were cut into ½-inch cubes twenty-nine, twenty-one, and eighteen minutes after adding rennet. The moisture content of the curds and the acidity of the wheys are shown in Tables 18 and 19. (See also fig. 15.)

TABLE 18.—*Moisture content of curds ripened to different degrees and pasteurized.*

| Time after cutting. | Moisture in curd. | | |
|---|---|---|---|
| | Vat I, acidity 0.177 per cent. | Vat II, acidity 0.21 per cent. | Vat III, acidity 0.26 per cent. |
| *Hrs. m.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 0 | 87.0 | 87.0 | 87.0 |
| 0 30 | 82.2 | 81.8 | 80.7 |
| 1 0 | 74.4 | 73.1 | 71.7 |
| 1 30 | 71.1 | 69.8 | 67.8 |
| 2 0 | .......... | 68.0 | 64.5 |
| 2 30 | 67.5 | 66.9 | 63.3 |

TABLE 19.—*Acidity of whey in cheese of Table 18.*

| Vat I. | | Vat II. | | Vat III. | |
|---|---|---|---|---|---|
| Time after cutting. | Acidity. | Time after cutting. | Acidity. | Time after cutting. | Acidity. |
| *Hrs. m.* | *Per cent.* | *Hrs. m.* | *Per cent.* | *Hrs. m.* | *Per cent.* |
| 0 0 | 0.125 | 0 0 | 0.14 | 0 0 | 0.18 |
| 0 55 | .125 | 2 35 | .142 | .......... | .......... |
| 2 5 | .125 | 3 0 | .153 | 2 30 | .19 |
| 3 0 | .137 | .......... | .......... | .......... | .......... |

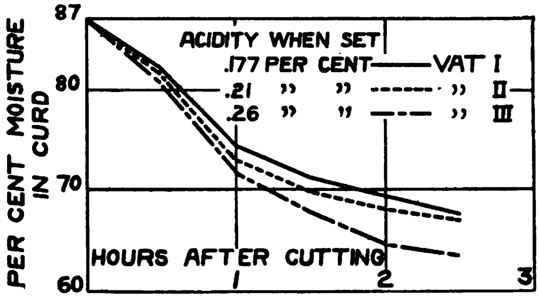

FIG. 15.—Effect of ripening milk to different degrees of acidity and then pasteurizing it before setting. The increase in the percentage of acid accelerated the rate of whey separation.

In this experiment the acidity of the surrounding whey was the same as the acidity of whey within the curd, since no increase of acidity occurred at any time after cutting the curd.

The curds with higher acid content gave up whey more rapidly than those of lower acidity. The moisture content fell more rapidly during the second half hour because the temperature was raised. After the first hour the moisture content decreased more slowly and did not go below 63 per cent in two and one-half hours after cutting.

### SEPARATION OF MOISTURE FROM CURD OF VARYING ACIDITY.

In this experiment four vats of milk were used. One was set as soon as possible at 0.17 per cent acidity and 86°. The second was held at 86° for one hour before setting, and, although the acidity was 0.17 per cent when set, the acidity of the whey rose faster after cutting than in vat I. In vat III the milk was ripened to 0.185 per cent, and in vat IV to 0.20 per cent before adding rennet. The curds were not stirred on the rack and were handled exactly alike. The acidity of the wheys and the moisture content of the curds at various intervals are given in Tables 20 and 21, and the effect of setting the milk at different degrees of ripeness is shown in figure 16.

TABLE 20.—*Moisture content of curds with varying ripeness.*

| Time after cutting. | Operation. | Moisture in curd. | | | |
|---|---|---|---|---|---|
| | | Vat I. | Vat II. | Vat III. | Vat IV. |
| *Hrs. m.* | | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 0 | ............ | 87.0 | 87.0 | 87.0 | 87.0 |
| 0 30 | ............ | 82.0 | 81.2 | 77.5 | 75.8 |
| 1 30 | ............ | 67.5 | 65.7 | 62.9 | 61.0 |
| 2 30 | Dipped... | 63.0 | 60.8 | 56.6 | 56.7 |
| 2 45 | ............ | 54.0 | 50.5 | 49.3 | 51.0 |
| 3 0 | ............ | 49.4 | 45.8 | 44.7 | 48.3 |
| 4 0 | Milled..... | 43.5 | 42.9 | 42.4 | 44.8 |
| 6 0 | Salted..... | 40.3 | 40.0 | 39.0 | 41.1 |
| 6 20 | Hooped... | 38.0 | 36.7 | 36.3 | 40.6 |

TABLE 21.—*Acidity of whey from curds of varying ripeness.*

| Vat I. | | Vat II. | | Vat III. | | Vat IV. | |
|---|---|---|---|---|---|---|---|
| Time after cutting. | Acidity. | Time after cutting. | Acidity. | Time after cutting. | Acidity. | Time after cutting. | Acidity. |
| *Hrs. m.* | *Per cent.* | *Hrs. min.* | *Per cent.* | *Hrs. min.* | *Per cent.* | *Hrs. min.* | *Per cent.* |
| 0 6 | 0.114 | 0 3 | 0.115 | 0 8 | 0.125 | 0 6 | 0.142 |
| 0 36 | .116 | 0 36 | .122 | 0 50 | .140 | 0 24 | .150 |
| 1 33 | .125 | 1 0 | .130 | 1 13 | .149 | 0 46 | .167 |
| 1 58 | .131 | 1 31 | .140 | 1 47 | .157 | 1 16 | .175 |
| 2 30 | .134 | 2 4 | .150 | 2 8 | .174 | 1 49 | .217 |
| | | | | 2 30 | .180 | 2 30 | .250 |

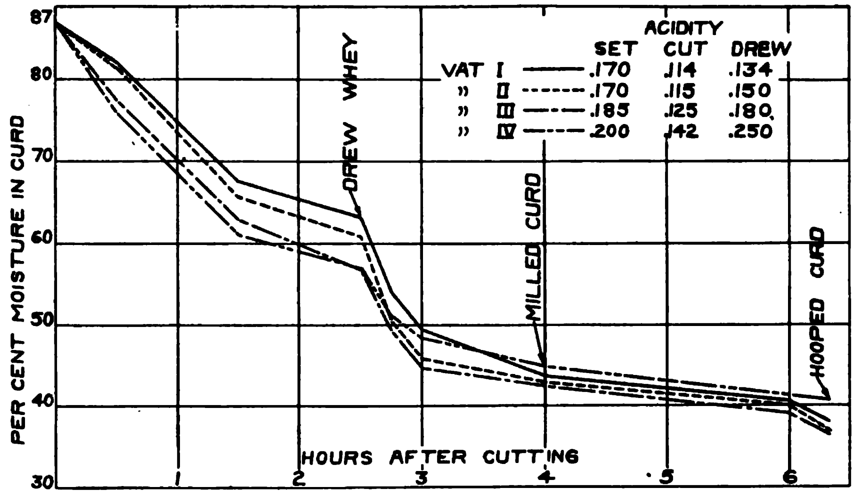

FIG. 16.—Effect of setting the milk at different degrees of ripeness. Curve IV is lower than curves I, II, and III at first, but crosses them between two and one-half and three and one-half hours after cutting and remains higher. This shows the characteristic tendency of high-acid curds to retain more moisture than curds of moderate acidity.

Where acidity is developing briskly in the curd, as in vat III, the moisture content of the curd falls readily to 58 per cent or less in two and one-half hours after cutting, but where there is little acid development, as in vat I, the moisture content falls more slowly.

The high proportion of acid in vat IV caused the curd to feel very soft at the time of dipping, though it had no more moisture at that time than the curd in vat III, which did not feel soft. The soft condition of curd in vat IV was probably due to the chemical influence of acid on the curd; it certainly was not due to excessive moisture.

The high-acid curd in vat IV lost moisture less rapidly on the rack than the others, so that when milled, salted, and hooped it had more moisture than those of medium acidity. This effect accompanied such high acidity in all cases.

In the preceding experiments the rate at which moisture separates from curd in the whey was shown to be more rapid at moderately high than at low acidity, but in this experiment it is seen that after the acidity of the whey passed above 0.18 per cent, as in vat IV, the rate of moisture separation was not proportionately increased. The curd in vat IV, when dipped at a whey acidity of 0.25 per cent, had no less a content of moisture than the curd in vat III, dipped at a whey acidity of 0.18 per cent.

Another similar experiment will be described in which the same effects produced by varying acidity can be seen. In this experiment four vats of milk were used. One was set at 0.16 per cent acidity, using no starter. The second was held at 86° for one hour and set at 0.17 per cent acidity. To the third 1 per cent of starter was added, and after ripening one and one-half hours it was set at 0.19 per cent. The fourth vat was ripened one and three-fourths hours with 2 per cent starter and set at 0.20 per cent. The acidity of the whey when drawn two and one-half hours after cutting was 0.13, 0.16, 0.21, and 0.27 per cent, respectively, in the four vats. The moisture content of the curds is given in Table 22. The curd in vat IV, set at 0.20 per cent and drawn at 0.27 per cent acidity, did not loose moisture any faster in the whey than vat III, which was set at 0.19 and drawn at 0.22 per cent acidity. (See fig. 17.)

TABLE 22.—*Moisture content of curds cut and firmed at various degrees of acidity.*

| Operation. | Acidity. | | | |
|---|---|---|---|---|
| | Vat I. | Vat II. | Vat III. | Vat IV. |
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| When set | 0.16 | 0.17 | 0.19 | 0.20 |
| When cut | .105 | .115 | .127 | .15 |
| When drawn | .13 | .16 | .22 | .27 |
| **Time after cutting.** | **Moisture.** | | | |
| *Hrs. m.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 0 | 87.0 | 87.0 | 87.0 | 87.0 |
| 0 30 | 81.2 | 79.1 | 79.5 | 78.9 |
| 1 10 | | 70.0 | 66.9 | 66.8 |
| 1 50 | 69.3 | 66.2 | | |
| 2 30 | 66.5 | 63.3 | 58.3 | 59.0 |

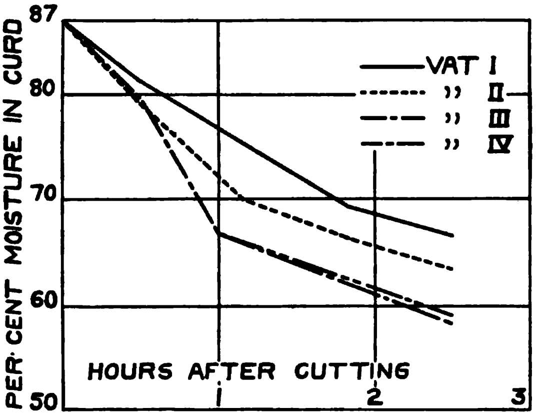

FIG. 17.—The same as figure 16, except that curd IV was riper.

In handling curds from overripe milk in a factory it should be remembered that when the whey acidity passes above 0.18 per cent the rate of separation of moisture from curd increases very little, if any, and there is little to be gained, as to firmness of curd, by prolonging the time that the curd remains in the whey. The very soft feeling which persists in a curd from overripe milk is often due to high acidity and not to excessive moisture.

## THE USE OF UNRIPENED MILK IN CHEESE MAKING.

The system of setting milk for Cheddar cheese with rennet while very sweet and without starter has gone out of use.[a] The method nearest to it among those now practiced is to add starter and set the milk without ripening, or to set the vat without starter, fairly sweet, in the belief that acidity will develop rapidly. In either of these cases the development of acid may be slower than expected, and sometimes it does not begin before the curd has been an hour or more in the whey.

In cases where acidity is lacking after cutting, the moisture content decreases fairly rapidly down to about 65 per cent, or a little more or less according to the temperatures and size of cubes, but below this figure the decrease is very slow. If rapid formation of acid begins late in the process, an increase in the rate of moisture separation may be observed, as was the case in the experiment shown in Table 23 and figure 18. The increased rate of moisture separation is shown in the figure by the downward bend of the curve at the time when the acidity began to increase rapidly, three hours after cutting.

**Table 23.**—*Rate of separation of moisture from curd when rapid development of acid begins late in the process.*

| Time after cutting. | | Moisture content of curd. | Acid content of whey. |
|---|---|---|---|
| *Hrs.* | *m.* | *Per cent.* | *Per cent.* |
| 0 | 0 | 87.0 | ............ |
| 0 | 30 | 80.5 | ............ |
| 0 | 48 | ............ | 0.115 |
| 1 | 0 | 73.8 | ............ |
| 1 | 30 | 68.8 | ............ |
| 2 | 0 | 66.7 | ............ |
| 2 | 10 | ............ | .128 |
| 2 | 30 | 65.2 | ............ |
| 3 | 0 | 64.0 | .137 |
| 3 | 30 | 62.4 | .145 |
| 4 | 0 | 59.4 | .155 |
| 4 | 30 | 56.9 | .172 |

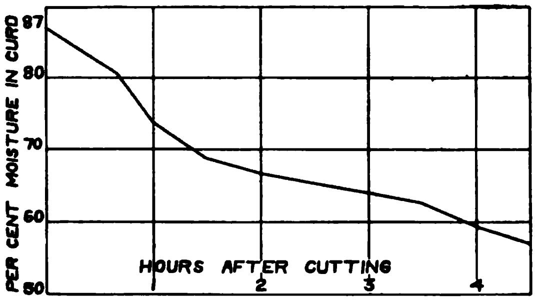

FIG. 18.—Showing increased rate of moisture separation due to rapid increase of acidity at late stage.

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[a] Arnold, L. B. American dairying. Rochester, N. Y., 1876. P. 327.

The figures show what takes place in a vat of milk in which little or no acid formation occurs immediately after cutting, such as is occasionally met with to-day, and also shows why the old-time cheese makers could leave a sweet-milk curd in the whey for a number of hours without getting an excessively dry cheese. In the absence of lactic acid, the removal of moisture from curd is automatically checked at about 65 per cent, and the effects of modifying the early steps of the process as to temperature and time and rate of heating the vat are practically obliterated in two hours after heating the vat. Examples of these are shown in tables 6 and 9.

The tenacity with which the remaining moisture is held is perhaps due to chemical attractions between the water and the other milk constituents. With the appearance of a new factor, lactic acid, whose presence introduces new attractions, the moisture readily falls to 50 or 55 per cent in the curd. At this point, again, the rate of moisture separation decreases, showing that, in general, the lower the moisture content falls the more tightly is the moisture held by the curd.

### THE USE OF PARTLY RIPENED MILK FOR CHEESE MAKING.

The system of regulating acidity most commonly employed since starters and acid and rennet tests came into use consists in getting the acidity up to 0.17 or 0.19 per cent in the milk and observing that an increase of acidity is really occurring in the vat before adding rennet, so that the operator has reason to believe that acid formation will continue at a fairly rapid rate after cutting.

The conditions of acidity at present sought are described more in detail at the beginning of this bulletin, and under these conditions the moisture content of curd falls fairly rapidly to about 50 or 55 per cent, instead of practically stopping at 63 to 68 per cent, as occurs with unripened milk curds. As previously stated, it is the custom at present to have about 0.17 per cent of acid in the whey by the time the curd is firm, but a smaller development of acid will suffice to bring down the moisture content to 55 per cent in the curd. Therefore, to insure so far as possible that 0.17 per cent of acid, instead of 0.15 per cent, for example, is present in the whey by the time the curd is firm enough to dip without unnecessary loss of fat, the cheese maker has to judge for himself before adding rennet whether acidity is increasing at a suitable rate.

### INFLUENCE OF PASTEURIZATION ON SEPARATION OF WHEY FROM CURD.

There is no question that pasteurization of the milk checks acid development in the curd. In addition, the heating of the milk may affect the constitution of the casein, or its relation to the water present, in such a way as to influence the ease and the rate of separating the whey. This point was tested in an experiment with three vats of milk. The milk in vat III was set at 0.17 per cent acidity, cut at 0.115 per cent, and three hours and fifteen minutes later the acidity had reached 0.135 per cent, showing that the rate of acid development was very slight. In vat II twice as much of the same lot of milk was placed and ripened with 1 per cent starter for two hours, which brought the acidity to 0.19 per cent. The acidity of the whey in vat II when cut was 0.14 per cent, and three hours and ten minutes later it was 0.24 per cent. Just before setting vat II, half of the milk was transferred from it to vat I and there heated rapidly to 150° and cooled. The heating required four minutes and the cooling twenty-five minutes. Each vat was set with 4 ounces of rennet per 1,000 pounds of milk at 86°, and the curds were cut, heated, and handled alike in all respects. The moisture content of the curd is shown in Table 24. (See also fig. 19.)

TABLE 24.—*Comparison of moisture content of curds from sweet, ripened, and pasteurized milk.*

| Time after cutting. | Vat III, sweet milk. | Vat II, ripe milk. | Vat I, pasteurized milk. |
|---|---|---|---|
| *Hrs. m.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 0 | 87.0 | 87.0 | 87.0 |
| 0 30 | 81.0 | 80.2 | 82.5 |
| 1 0 | 75.1 | 69.4 | 75.0 |
| 1 30 | 71.5 | 63.3 | 70.9 |
| 2 30 | 70.0 | 60.5 | ............ |
| 2 30 | ............ | ............ | 68.0 |
| 3 0 | 66.7 | 56.4 | ............ |
| 3 30 | ............ | ............ | 65.5 |
| 4 0 | 61.8 | ............ | ............ |

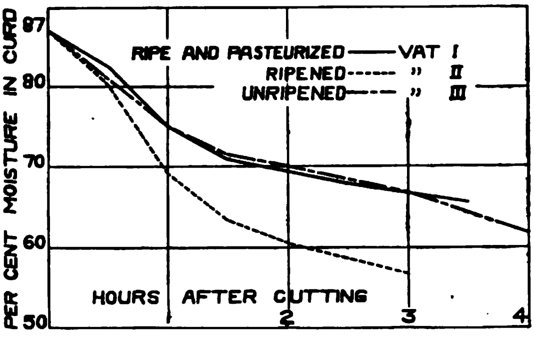

FIG. 19.—Effect of sweet, ripe, and ripe pasteurized milk on rate of moisture separation.

The milk in vat I, set at 0.19 per cent acidity, after pasteurizing gave up its whey at about the same rate as the sweet milk in vat III set at 0.17 per cent. There was a slight increase of whey acidity in vat III, but none in vat I. From this it appears that the rate at which moisture separates from curd when the milk is pasteurized is about the same as when the milk is sweet and practically uninoculated with bacteria.

Further study of the relation of pasteurization to cheese-making is in progress and will be reported later.

### EFFECT OF PRESSURE ON MOISTURE CONTENT OF CURD.

It is generally supposed that pressure applied to the curd in the press does not drive moisture from the interior of the curd cubes, but removes only that which is on the surface. The following quotation from Decker[a] expresses the facts, so far as they could be observed in the course of ordinary factory work:

> The idea that we make a cheese dry by pressing it is an erroneous one. The whey must be removed from the curd while it is in the vat; if it is not, no amount of squeezing in the press will expel it.

While it is impossible to get a very moist curd dry and firm by ordinary squeezing in the press, yet a notable proportion of water is removed by pressure, as shown by the following experiment: Four curds were sampled just before hooping, by use of the sharp brass sampling tube. Two portions of each sample were placed in tin boxes and weighed. Two similar portions were carefully wiped, piece by piece, with filter paper, then placed in boxes and weighed. The filter paper removed all surface moisture. The next morning, as soon as the curds came out of the press, they were sampled again with an ordinary cheese trier at a point about halfway between the center and the edge. The samples were all dried in the oven at the same time. The results show that the loss by wiping is on the average 0.3 per cent and by pressing 4.1 per cent, and that about 3.8 per cent of moisture removed in the press was not superficial at the time of hooping.

TABLE 25.—*Loss of moisture caused by wiping and by pressing curds.*

| Operation. | Moisture in curd. | | | |
|---|---|---|---|---|
| | Vat I. | Vat II. | Vat III. | Vat IV. |
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Sample as hooped | 37.4 | 37.1 | 37.9 | 38.8 |
| Sample after wiping | 36.8 | 37.0 | 37.8 | 38.5 |
| Sample after pressing | 31.7 | 33.3 | 33.9 | 34.9 |

Exact moisture determinations show that pressure in the hoop does remove notable proportions of moisture held superficially and otherwise by the curd when hooped.

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[a] Loc. cit., p. 87.

Respecting the influence of pressure on curd in the vat Lloyd[a] wrote, in 1899, after describing methods used in England:

> The chief and characteristic difference between various methods of cheese making depends on the course taken to obtain the curd sufficiently dry. At this time, 1857, only two methods were known, the one by use of heat, the other by the use of pressure. The latter was the system of Joseph Harding, the curd being subjected to pressure in the vat before being finally ground and pressed into a cheese.

### LOSS OF MOISTURE BY PRESSURE AFTER PUTTING CURD ON RACK.

In many of the experiments already described[b] it can be seen that during the first fifteen to thirty minutes after the curds were out of the whey and piled up without stirring the moisture content fell more rapidly than while they were in the whey. At this stage the superficial moisture drains away from the cubes, and a considerable amount of moisture which is not superficial, that is, which can not be removed by bibulous paper, is also driven out. Under the pressure of the piled curd the cubes at the bottom of the mass quickly lose their regular cubical shape and pack together, like figs in a box, so closely as to prevent the free drainage of whey through the bottom of the curd. The distorted, packed cubes coalesce more or less quickly, forming a single mass in which the boundaries of the separate cubes can not be distinguished. This entire process of packing and coalescing is called "matting" by the cheese maker. The middle layer of the mass mats more slowly, and the matting of the top layer is completed a few minutes later by turning the curd mass upside down, thus putting it under pressure.

The separation of whey from a single large mass of curd, such as an uncut curd, is exceedingly slow. It has already been shown that the smaller the pieces into which a curd is cut the more rapid is the rate of whey separation. The converse may be taken for granted, namely, that when the curd cubes coalesce to a single mass the separation of moisture is markedly checked. If the cause of the rapid loss of moisture on the rack is the pressure of curd particles on each other, then it should be possible to remove moisture from curd by application of pressure to the curd under the whey.

### LOSS OF MOISTURE BY PRESSING THE CURD UNDER THE WHEY.

In the following experiment three vats of milk containing 200 pounds each were set at 0.16 per cent acidity, cut alike, and heated in thirty-five minutes to 104°. The whey in vat I was drawn two and one-half hours after cutting and the curd put on the rack in the usual manner, the whey acidity being 0.125 per cent. In vat II the curd and whey were scooped into a 15-inch Cheddar cheese hoop containing some curd cloth and set in the vat two hours after cutting. A circular board, the follower, was put on the curd, and a 25-pound weight placed on top. The follower was removed at intervals of four minutes, the curd being stirred up and sampled and then put under pressure again.

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[a] Loc. cit., p. 12.

[b] See figures 1, 3, 7, 9, 10, 11, 15.

A reduction of moisture content from 65.9 to 52.8 per cent was effected by this means in vat II in thirty minutes. During this time the curd in vat I had decreased from 65.3 to 63.9 per cent in moisture. As it would not be convenient to apply pressure in this manner to the curd in a large vat, an effort was made to reduce the moisture content of the curd in vat III by drawing off a large proportion of the whey two hours after cutting. The whey was left about 1 inch deep, and the curd stood 2 or more inches above the whey. By occasional stirring the curd was prevented from matting. The moisture content fell from 66.1 to 55.6 per cent in one-half hour, and the method seemed to be quite effective as a means of rapidly reducing the moisture content of a soft curd just before putting the curd on the rack. The details are shown in Table 26 and figure 20.

TABLE 26.—*Effect of pressure on moisture content of curd in the vat.*

| Time after cutting. | | Operation. | Moisture in curd. | | |
|---|---|---|---|---|---|
| | | | Vat I (put on the rack in the usual manner). | Vat II (external pressure applied while curd was under the whey). | Vat III (whey mostly removed, leaving curd under its own pressure for half an hour before dipping). |
| *Hrs.* | *m.* | | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 | 30 | | 78.6 | 79.8 | 79.0 |
| 1 | 0 | | 71.3 | 71.2 | 71.3 |
| 1 | 30 | | 66.8 | 68.0 | |
| 2 | 0 | | 65.3 | 65.9 | 66.1 |
| 2 | 10 | | | 58.6 | 60.6 |
| 2 | 30 | Dipped | 63.9 | 52.8 | 55.6 |
| 4 | 0 | Milled | 41.7 | 40.6 | 41.5 |
| 5 | 0 | Hooped | 39.0 | 40.0 | 38.8 |

The only reference to such a method which the writer has been able to find in the literature is the following by Waddell and McKay,[a] who say in giving instructions for making cheese from overripe milk:

> Run off the whey as soon as possible and stir the curds well in the small amount of whey before dipping, so as to have the curds well firmed before sufficient acid is developed.

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[a] Waddell, W., and McKay, A. Hints on the care of milk for creameries and cheese factories, and Canadian Cheddar cheese making. In Dairy School Bulletin 143 of the Ontario Agricultural College and Experimental Farm, pp. 1–56. Toronto, 1905. See p. 34.

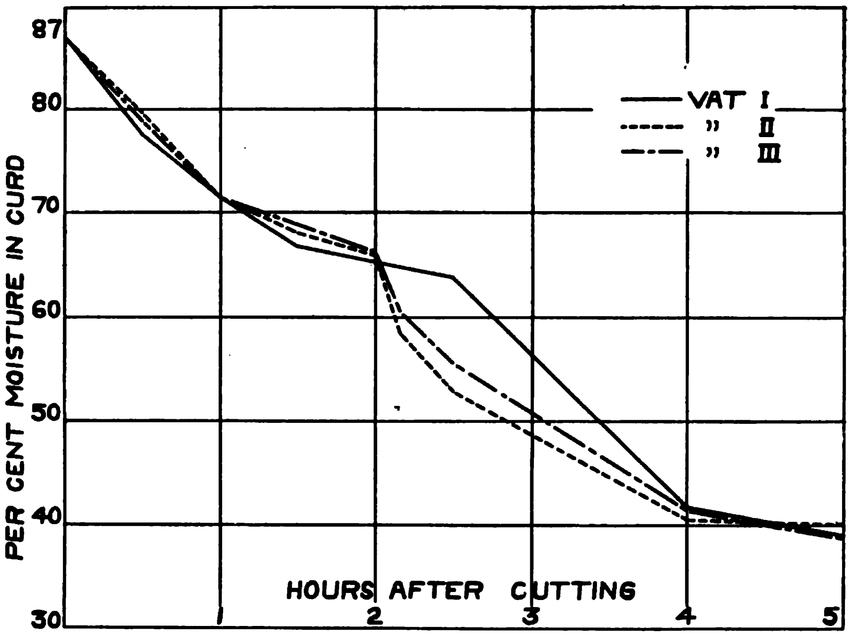

FIG. 20.—Effect of pressure on the moisture content of curd. Curves II and III show how the moisture content of a curd in the whey was reduced by applying external pressure for a few minutes. Compare with curve I, made without pressure.

These writers do not say how effective the method is in removing moisture, nor do they show that the level of the whey must go below the curd level to produce the desired result.

## SELF-PRESSURE OF CURD IN THE WHEY—COMPARISON OF SHALLOW AND DEEP VATS.

Cheese makers often ask whether the pressure of curd particles on each other when allowed to settle in the whey is sufficient to drive out whey from the curd. The curd cubes while in the whey are buoyed up by the liquid to such an extent that they exert only a very slight pressure on each other at the bottom of the vat. The specific gravity of the curd is about 1.045 and of the whey 1.021 at the temperature of the vat; therefore a piece of curd weighing 1.045 grams in the air weighs 1.045 – 1.021, or about 0.024 gram when under the whey, which is about one forty-third of its weight in air. Consequently it should not be expected that the pressure of curd particles on each other when allowed to settle under the whey would have much influence on the moisture content. The facts are shown by the following experiment:

Two vats were used, one containing 200 pounds of milk and one containing 600 pounds. The milk in the first stood 6 inches deep and in the other 18 inches. It tested 4 per cent fat and 0.175 per cent acidity, and was all taken from the same lot of mixed milk. The two vats had the same dimensions excepting in depth, and the milk in the vats was handled exactly alike in all respects. It was set with 4 ounces of rennet per 1,000 pounds at 86°. Each curd was cut into ½-inch cubes fifteen minutes after adding rennet. Fifteen minutes later steam was turned on and the vats were heated to 104° in twenty minutes. They were carefully maintained at this temperature and were sampled at thirty-minute intervals. After heating, the curds were stirred regularly at fifteen-minute intervals and allowed to settle between times. Under these circumstances the layer of whey and of curd in the second vat was as deep as commonly occurs in a factory vat, while that in the first vat was only one-third as deep. If the pressure of the curd particles on each other under the whey is an important factor in the separation of moisture from curd in ordinary cheese making, there should have been a noticeable difference between the moisture content of these two curds. There was, however, no difference, as is shown in Table 27.

TABLE 27.—*Moisture content of curds made in deep and shallow vats.*

| Time after cutting. | Moisture in curd. | |
|---|---|---|
| | Vat I (milk 6 inches deep). | Vat II (milk 18 inches deep). |
| *Hrs. m.* | *Per cent.* | *Per cent.* |
| 0 0 | 87.0 | 87.0 |
| 0 30 | 79.9 | 78.4 |
| 1 0 | 67.3 | 67.8 |
| 1 30 | 64.0 | ........... |
| 2 0 | 60.2 | 60.9 |
| 2 30 | 57.7 | 56.3 |

From this and similar experiments it was concluded that the pressure of curd particles on each other at the bottom of the cheese vat is not sufficient to hasten the removal of moisture from the curd. There was no difference between the results obtained with 200 pounds and with 600 pounds, and it seems reasonable to believe that the results obtained in small experimental vats would be obtained with any sized vat if handled in the same way.

### EARLY REMOVAL OF PART OF WHEY FROM VAT.

Cheese makers often drain off a large proportion of the whey above the curd quite early in the process after cutting. The remainder of the whey being less in volume can then be removed more quickly when the curd is ready to mat.

In his work on "Canadian Dairying," Professor Dean[a] gives the following directions: "In summer, it is wise to remove most of the whey from the curd soon after heating in order to better control the development of acid."

The question has been asked whether the early removal of part of the whey from the vat has any influence on the rate at which the curd gives up moisture. To answer this question the following experiment was tried repeatedly with both sweet and ripened milk, and always with the same conclusion. Two vats of mixed milk testing 4 per cent fat and 0.180 per cent acidity were set at 86° with 4 ounces of rennet per 1,000 pounds. The curds were cut into ½-inch cubes twenty-five minutes later, and heat was applied to each fifteen minutes after cutting, reaching 104° twenty minutes later.

The vats were handled exactly alike in all respects excepting that a strainer was placed in vat I and a slow stream of whey was started by partly opening the gate twenty-four minutes after cutting. The whey was caught in buckets, and the weight and time of filling each bucket were recorded. Care was exercised to draw the whey no lower than the top of the curd, in order that the curd particles might always have the buoying effect of the surrounding liquid. The time of each operation, the weight of whey removed from vat I, the moisture content of the curds, and the acidity of the whey in each vat are given in Tables 28 and 29 and figure 21.

**TABLE 28.**—*Influence of early removal of part of whey from vat—Comparison of acidity.*

| Time after cutting. | | Whey removed from vat I. | | Acidity of whey in vat I. | Acidity of whey in vat II. |
|---|---|---|---|---|---|
| | | Total weight. | Proportion of vat contents. | | |
| *Hrs.* | *m.* | *Pounds.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 | 0 | | | 0.13 | 0.13 |
| 0 | 29 | 23 | 11.5 | | |
| 0 | 34 | 45 | 22.5 | | .14 |
| 0 | 40 | | | .14 | |
| 0 | 53 | 67 | 33.5 | | |
| 1 | 5 | | | .155 | .152 |
| 1 | 15 | 89.5 | 44.75 | .165 | |
| 1 | 25 | | | | .161 |
| 1 | 30 | | | .172 | |
| 1 | 45 | | | .20 | |
| 1 | 50 | 104 | 52 | | |
| 2 | 0 | | | | .177 |
| 2 | 5 | | | .215 | |
| 2 | 20 | | | | .197 |
| 2 | 25 | | | .237 | |
| 2 | 30 | | | .260 | .200 |

[a] P. 165.

**Table 29.**—*Influence of early removal of part of whey from vat—Comparison of moisture content of curd.*

| Time after cutting. | | Operation. | Moisture in curd. | |
|---|---|---|---|---|
| | | | Vat I. | Vat II. |
| *Hrs.* | *m.* | | *Per cent.* | *Per cent.* |
| 0 | 30 | | 79.4 | 78.6 |
| 1 | 0 | | 68.1 | 69.3 |
| 1 | 30 | | 64.6 | ........ |
| 1 | 40 | | ........ | 61.9 |
| 2 | 30 | Dipped | 56.5 | 55.2 |
| 3 | 0 | | 45.7 | 44.1 |
| 4 | 0 | Milled | 42.8 | 41.5 |
| 6 | 0 | Salted | 39.0 | 38.8 |
| 6 | 20 | Hooped | 36.4 | 36.5 |

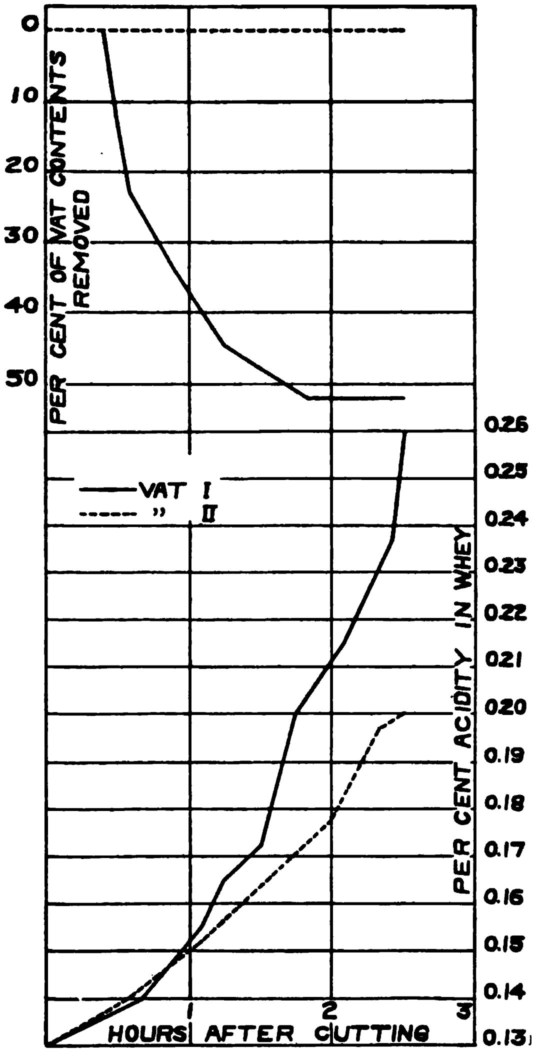

Fig. 21.—Effect of removal of whey on acidity.

No starter was used. The milk was well mixed before use and the vats were handled alike, so that it is certain that the amounts of acid formed by the bacteria in the two vats were alike. The acidity of the whey in vat I rose to 0.26 per cent in the same length of time that it rose to 0.20 per cent in vat II because the volume of whey in vat I was reduced to less than half the volume in vat II. The moisture content of the two curds was practically identical throughout.

From this and similar experiments it is concluded that the rate of separation of moisture from the curd is not affected by early removal of part of the whey from the vat if the curd is kept covered with whey. Where the acidity is developing rapidly in the curd and acid is passing from the curd into the whey, the acidity of whey in the vat increases more rapidly after a portion is drawn off than if none is removed. The smaller the bulk of whey surrounding the curd the higher its percentage of acidity will be raised by the transfer of a given weight of lactic acid from curd to whey. Therefore a cheese maker who relies upon the titration of whey with a standard alkaline solution for an indication of the acid development in the curd is likely to be misled and to imagine that the acidity of the curd is higher than it really is, if he has drawn off a considerable proportion of the whey early in the process and is titrating what is left in the vat. The later in the process the whey is drawn down the less important this source of error becomes, and where the whey gate is large, or where both siphon and whey gate are used, the whey need not be drawn down early and no such mistake need occur.

## STIRRING THE CURD ON THE RACK.

It is the regular custom in many factories to stir the curd after piling it on the rack or on the bottom of the vat. Stirring prevents the curd cubes from packing together and permits them to drain longer and more completely before coalescing. It may be that the kneading and rubbing which the curd receives during the process of stirring on the rack hastens the loss of moisture, as additional pressure would do. The effect of stirring is especially marked where curds when dipped are soft and weak, from either excessive moisture or excessive acid, or other cause, so that they tend to mat rapidly and stop draining if not stirred.

On the rack the moisture content of curds falls rapidly at first, but afterwards the fall rapidly decreases. Below 45 per cent it falls very slowly, and it is very difficult by stirring for any length of time to reduce it below 35 per cent. The curd holds this proportion of moisture with great tenacity.

### EFFECT OF STIRRING ON CURDS OF EQUAL ACIDITY BUT VARYING MOISTURE CONTENT.

Whatever be the stage of the process of firming in the whey when the curd is put on the rack, its moisture content can be quickly reduced by stirring, as is shown in the following experiment: Four vats of milk of 0.185 per cent acidity and 4.1 per cent fat content were heated to 86°, ten minutes apart, and were set one-half hour apart. The wheys were drawn ten minutes apart, when the curds had been in the whey one, one and one-half, two, and two and one-half hours, respectively, and contained 56 to 63 per cent water. The curds were put on the rack in each case three hours from the time the milk was heated. This was done in order that the four vats might be equally ripened at this stage. The whey acidity was 0.20 per cent. Each curd was stirred for eight minutes after it started on the rack. By stirring, the moisture content was reduced within half an hour after drawing to between 41.2 and 43.5 per cent in each of the curds. It appears from this that between one and two and one-half hours after cutting the whey can be drawn at any time when acidity or other conditions make it desirable, and the moisture content can be properly reduced by stirring on the rack. (See Table 30 and fig. 22.)

TABLE 30.—*Effect of stirring on curds of equal acidity but varying moisture content when dipped.*

| Time after cutting. | | Moisture in curd. | | | |
|---|---|---|---|---|---|
| | | Vat I (cut to draw 2½ hours). | Vat II (cut to draw 2 hours). | Vat III (cut to draw 1½ hours). | Vat IV (cut to draw 1 hour). |
| *Hrs.* | *m.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 | 30 | 78.0 | 78.2 | 76.6 | 76.4 |
| 1 | 0 | | 64.5 | 64.1 | [a] 62.4 |
| 1 | 10 | 65.2 | | | |
| 1 | 30 | | 60.0 | [a] 60.0 | 43.1 |
| 1 | 50 | 59.5 | | | |
| 2 | 0 | | [a] 58.0 | 43.1 | 42.7 |
| 2 | 30 | [a] 56.8 | 42.7 | | |
| 3 | 0 | 43.5 | | 41.2 | 41.2 |
| 3 | 30 | | 40.6 | 40.4 | [b] 38.8 |
| 4 | 0 | 39.8 | 39.7 | [b] 37.9 | |
| 4 | 30 | 39.0 | [b] 37.1 | | |
| 5 | 0 | [b] 37.4 | | | |

[a] Sample taken just before drawing whey.
[b] Sample taken when the curd was hooped.

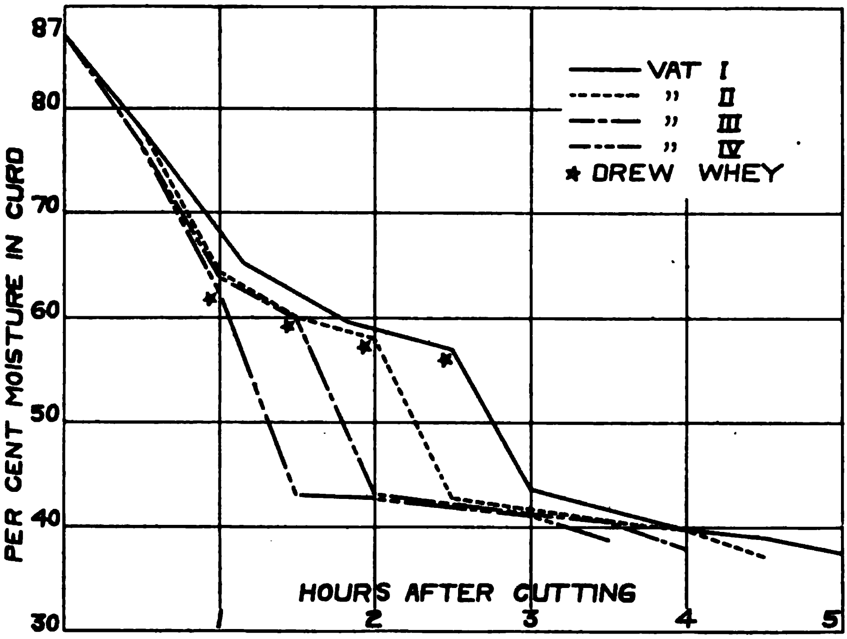

FIG. 22.—Effect on moisture of different times for dipping.

This experiment illustrates the fact that by stirring about eight minutes on the rack the moisture content of curds of equal acidity but of moisture content varying from 56 to 63 per cent can all be brought finally to the same figure. The moisture content when hooped depends very little on the moisture content just before dipping, if such curds are well stirred on the rack.

## EFFECT OF STIRRING CURDS OF DIFFERENT ACIDITY.

In another experiment four vats of milk of 0.185 per cent acidity and 4 per cent fat were heated to 86° and set ten minutes apart. The whey was drawn one, one and one-half, two, and two and one-half hours, respectively, after cutting, when the acidity was 0.162, 0.17, 0.18, and 0.20 per cent. The curds were stirred eight minutes on the racks and were handled alike in all other respects. The moisture content of the curds varied from 56 to 67 per cent just before drawing the whey, and when hooped varied from 35 to 39 per cent. The curd of lowest acidity, when dipped, retained the most moisture after stirring and when hooped.

The conditions were precisely the same as in the last experiment described excepting that in the present instance both the acidity and the moisture content varied when the whey was drawn, while in the other case the acidity was alike in all four vats and the moisture varied when dipped. In consequence, when the curds were hooped the moisture varied in the present experiment, but not in the previous one. When hooped, the moisture content of a curd which was well stirred on the rack is independent of the moisture content when dipped, but is influenced to a notable degree by the acidity, curds of low acidity retaining more moisture than those of moderately high acidity. It has already been shown that curds of low acidity lose moisture while in the whey more slowly than curds of moderately high acidity. (See Table 31 and fig. 23.)

TABLE 31.—*Effect of stirring on moisture content of curds of varying acidity and moisture content.*

| Time after cutting. | | Moisture in curd. | | | |
|---|---|---|---|---|---|
| | | Vat I (cut to draw 2½ hours). | Vat II (cut to draw 2 hours). | Vat III (cut to draw 1½ hours). | Vat IV (cut to draw 1 hour). |
| *Hrs.* | *m.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 | 30 | 77.9 | 78.8 | 78.7 | 77.8 |
| 1 | 0 | ........... | 68.8 | 69.8 | [a] 67.0 |
| 1 | 15 | ........... | ........... | ........... | 48.0 |
| 1 | 30 | 63.3 | ........... | [a] 61.2 | 45.3 |
| 1 | 45 | ........... | ........... | 48.1 | ........... |
| 2 | 0 | ........... | [a] 58.9 | 42.8 | ........... |
| 2 | 15 | ........... | 47.5 | ........... | ........... |
| 2 | 30 | [a] 56.6 | 43.2 | ........... | 41.5 |
| 2 | 45 | 47.1 | ........... | ........... | ........... |
| 3 | 0 | 43.0 | ........... | 39.2 | 39.2 |
| 3 | 30 | ........... | 39.0 | 40.0 | [b] 39.3 |
| 4 | 0 | 38.9 | 38.8 | [b] 36.9 | ........... |
| 4 | 30 | 38.7 | [b] 36.2 | ........... | ........... |
| 5 | 0 | [b] 35.0 | ........... | ........... | ........... |

[a] Sample taken just before drawing the whey.
[b] Sample taken when the curd was hooped.

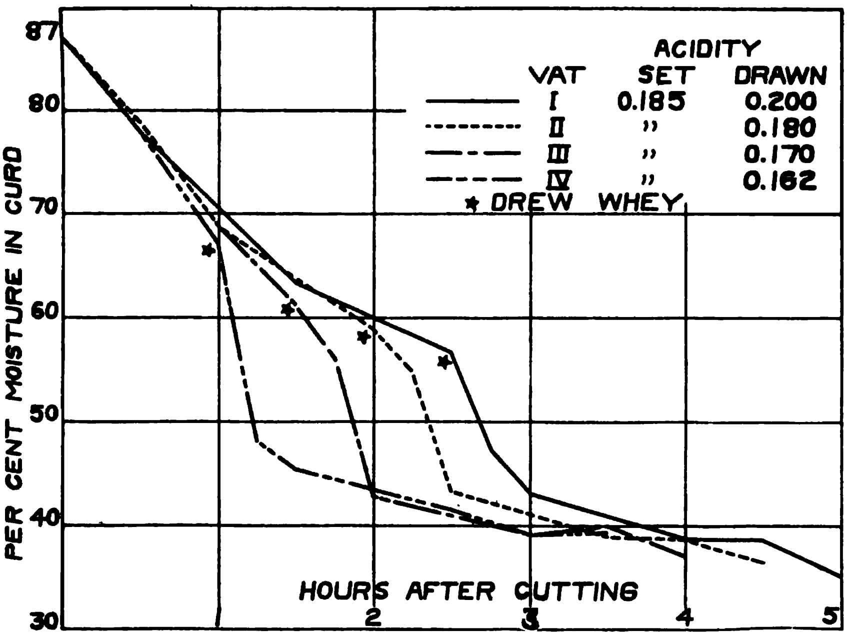

FIG. 23.—Effect of stirring the curd on the racks. Curds of unequal acidity when dipped are not brought to the same moisture content by stirring on the rack.

## INFLUENCE OF FAT CONTENT OF CURD ON MOISTURE SEPARATION.

To determine whether curd gives up water more or less rapidly when the fat content is varied, several experiments were performed in the following manner: Eleven hundred pounds of whole milk of 0.165 per cent acidity and 4.3 per cent fat was collected in one vat and enough of it was run through a cream separator to furnish 400 pounds of skim milk, which was placed in another vat and mixed thoroughly. Portions of the skim milk and the whole milk were then weighed into the experimental vats, as indicated in Table 32. The vats were all heated to 86° and set with 3 ounces of rennet per 1,000 pounds. The curds were cut into one-half inch cubes and were heated in a uniform manner, beginning fifteen minutes after cutting, and reaching 104° twenty minutes later. The curds were sampled at intervals and moisture determinations were made on the samples as shown in Table 32 and figure 24.

Table 32.—*Moisture in curds containing different proportions of fat.*

| Content. | Vat I. | Vat II. | Vat III. | Vat IV. |
|---|---|---|---|---|
| Whole milk.......pounds.. | 200 | 133 | 67 | None. |
| Skim milk...........do.... | None. | 67 | 133 | 200 |
| Fat determined..per cent.. | 4 3 | 3.0 | 1.7 | 0.07 |
| Time after cutting. | Moisture in curd— | | | |
| *Hrs.* *m.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 30.................... | 82.6 | 82.4 | 83.5 | 87.8 |
| 1 0.................... | 72.5 | 75.8 | 80.1 | 81.8 |
| 1 30.................... | 69.7 | 72.0 | 75.6 | 79.3 |
| 2 0.................... | 66.7 | 70 3 | 73.7 | 78.8 |
| 2 30.................... | 64.2 | 68.1 | 71.8 | 76.1 |

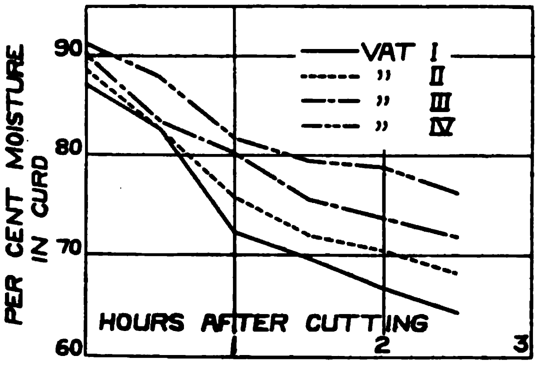

Fig. 24.—Effect of varying the fat content of the milk used.

It appears from the figures that the moisture content of curd I, containing the largest proportion of fat, fell to 64.2 per cent, while that in vat IV only fell to 76.1 per cent. In this form, however, the results are not strictly comparable, since the figure representing the percentage of moisture in vat I depends not only upon the moisture present but also upon the proportion of fat. The larger the proportion of fat present, the smaller the proportion of moisture will appear. In order to make the results comparable they should all be calculated to a fat-free basis. In order that this might be done, parts of the curd samples taken for moisture determinations were used also for duplicate fat determinations by the Babcock test.

The percentage of moisture in the curd divided by 1 minus the per cent of fat in the curd gives the percentage of moisture in the fat-free curd. The percentages of fat in the curd and of moisture in the fat-free curd are given in Table 33 and figure 25.

TABLE 33.—*Fat content of curds and moisture content of fat-free curds.*

| Time after cutting. | Fat content. | | | |
|---|---|---|---|---|
| | Vat I. | Vat II. | Vat III. | Vat IV. |
| *Hrs. m.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 1 30 | 18.8 | 14.4 | 9.72 | ............ |
| 2 00 | 21.3 | 16.0 | 10.9 | ............ |
| 2 30 | 21.5 | 15.9 | 10.3 | 1.2 |
| | Moisture in fat-free curd. | | | |
| 1 30 | 85.8 | 84.1 | 83.7 | 80.2 |
| 2 00 | 84.7 | 83.7 | 82.1 | 79.7 |
| 2 30 | 81.8 | 80.9 | 80.0 | 77.0 |

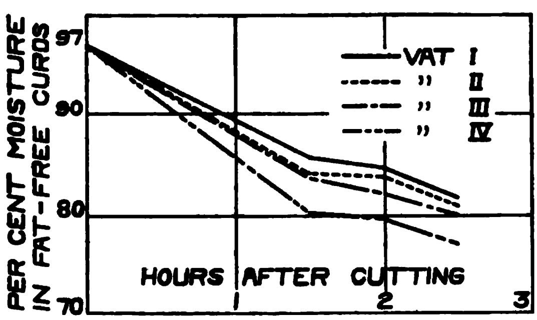

FIG. 25.—Effect of presence of fat on the moisture content of curds reduced to a fat-free basis. The presence of fat slightly delays the separation of moisture from the curd. Within natural limits of variation of fat content in herd milk, the effect is very small, as shown by vats I and II.

In this form the results show clearly that the moisture is removed more rapidly from the curds with the smaller content of fat. The fat by its presence somewhat delays the separation of moisture from casein. The same conclusion was reached by a different method, based on the weight of the green cheese obtained in the different vats and the ratio of moisture to casein in each cheese. The moisture was determined by the usual method in plugs drawn after the cheese had been taken from the press and weighed. The weight of water in the cheese is obtained by multiplication of the weight of cheese by the percentage of moisture. The weight of casein in each cheese is calculated in the following manner: In vat I the whole milk contained 4.3 per cent fat, and the casein calculated by Van Slyke's formula (no direct casein determination having been made) is 2.62 per cent. There was, therefore, about 8.6 pounds fat and 5.24 pounds casein in vat I and in the cheese made therein. Vat II contained 3.1 per cent fat, or 6.2 pounds, which is 2.4 pounds less fat than vat I. As all of the vats contained the same weight—200 pounds of milk—vat II consequently contained 2.4 pounds more of fat-free liquid than vat I. About 2.62 per cent, or 0.06 pound casein, is present in 2.4 pounds of milk, and therefore the casein content of vat II was 5.24 + 0.06 = 5.30 pounds.

In a similar manner the weight of casein in vats II, III, and IV are found to be 5.30, 5.37, and 5.46 pounds, respectively.

TABLE 34.—*Casein and moisture content of green cheese.*

| | Vat I. | Vat II. | Vat III. | Vat IV. |
|---|---|---|---|---|
| Fat in milk ... per cent. | 4.3 | 3.0 | 1.7 | 0.07 |
| Weight of green cheese ... pounds. | 21.2 | 18.5 | 15.7 | 13.0 |
| Moisture found ... per cent | 37.4 | 41.2 | 45.0 | 51.7 |
| Water present ... pounds. | 7.93 | 7.62 | 7.06 | 6.72 |
| Casein present ... do. | 5.24 | 5.30 | 5.37 | 5.46 |
| Water per pound of casein ... do. | 1.51 | 1.44 | 1.31 | 1.23 |

Since the ratio of moisture to casein was the same in the four curds when cut and is found to be greatest, after pressing, in the green cheese containing the most fat, it follows that the separation of moisture from the curd has been delayed by the presence of fat.

Curd I had lost a smaller proportion of its moisture and therefore felt softer when grasped in the hand than the other curds. It contained more fat than the others, which also tended to make it feel softer. Although the milk was all taken from the same vat just before the experiment, it was found that the acidity of the whey when drawn was not quite uniform in the four vats. In this experiment the whey acidity was 0.13, 0.127, 0.125, and 0.12 per cent, respectively, in vats I, II, III, and IV, two and one-half hours after cutting. The effect of the slightly greater acidity in vat I would be to hasten slightly the separation of moisture from the curd in this vat, but this effect was entirely masked by the presence of the fat, which delayed the moisture separation to a greater degree.

## INFLUENCE OF VARIATIONS IN THE PROPORTION OF CASEIN IN THE CURD.

In order to vary the casein content while retaining practically uniform fat content, separator skim milk containing 0.05 per cent of fat was mixed with different proportions of distilled water in the different vats. Vat I contained 200 pounds of milk, vat II contained 183 pounds of milk and 17 pounds of water, vat III contained 167 pounds of milk and 33 pounds of water, and vat IV contained 150 pounds of milk and 50 pounds of water. The casein varied as the numbers 1, 0.91, 0.83, and 0.75 in the four vats. The liquids began to thicken fourteen, sixteen and one-half, nineteen, and twenty-one and one-half minutes after adding 4 ounces of rennet per 1,000 pounds at 86°.

The curds were cut one hour and twenty-five minutes after adding rennet, at which time curd IV was not very stiff and did not seem to be improving.

Comparing vats I and IV as to content of water and solids, it is evident that the latter contained 50 pounds of water in place of 50 pounds of milk in vat I. The 50 pounds of milk in vat I contained about 6 pounds of milk solids, which was replaced in vat IV with 6 pounds of water. Therefore the water content of vat IV was about 6 pounds (or 3 per cent) greater than that of vat I.

The water content of vat I, when set, was about 90 per cent, while that of vat IV was 93 per cent, and vats II and III lay between these figures. Starting with these small differences of moisture content, the curds with the largest moisture content gave up moisture slightly more rapidly during the first hour, after which there was practically no difference in the percentage of moisture contained in the four curds, as shown in Table 35.

TABLE 35.—*Influence of variations in casein content on rate of moisture separation.*

| Time after cutting. | Moisture in curd. | | | |
|---|---|---|---|---|
| | Vat I. (Milk, 200 lbs.; water, 0 lbs.) | Vat II. (Milk, 183 lbs.; water, 17 lbs.) | Vat III. (Milk, 167 lbs.; water, 33 lbs.) | Vat IV. (Milk, 150 lbs.; water, 50 lbs.) |
| *Hrs. m.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 40 | 86.0 | 85.6 | 86.4 | 85.0 |
| 1 0 | 81.8 | 82.1 | 81.2 | 82.5 |
| 1 30 | 79.0 | 79.1 | 79.5 | 79.2 |
| 2 0 | 76.0 | 76.9 | 76.7 | 76.2 |
| 2 30 | 75.0 | 74.8 | 76.1 | 74.5 |

The casein content of vat IV was three-fourths that of vat I, so that the ratio of moisture to casein was one and one-third times as great in curd IV as in curd I when cut, but this difference had entirely disappeared one hour after cutting. Increase in the ratio of moisture to casein in milk produces corresponding increase in the initial rate of moisture separation after cutting, thus tending always to produce curds of uniform relative proportions of moisture and casein.

### EFFECT OF DILUTING MILK WITH WATER ON SEPARATION OF MOISTURE FROM CURD.

The natural variations of water content in milk may be simulated by adding proper proportions of water to normal milk. The effect of the addition of water upon the rate of moisture separation from curd is shown in the following experiment:

In order to maintain constant acidity, 1,100 pounds of whole milk containing 3.9 per cent fat and 2.85 per cent casein and of acidity 0.172 per cent was pasteurized at 150° in the Farrington duplex pasteurizer. After mixing the product thoroughly, 200 pounds were placed in vat I, 190 pounds with 10 pounds of distilled water in vat II, and 170 pounds with 30 pounds of water in vat III. Thus, vat II contained about 1.3 pounds and vat III about 4 pounds more water than vat I. The fat in vats II and III was, respectively, 3.7 and 3.3 per cent. The vats were heated to 86° and set with 4 ounces of rennet per 1,000 pounds. They were top stirred and cut, and were heated to 104° in thirty-five minutes and handled exactly alike in all respects. The moisture content of each curd is shown in Table 36.

TABLE 36.—*Separation of moisture from curd made from normal and from diluted milk.*

| Time after cutting. | | Moisture in curd. | | |
|---|---|---|---|---|
| | | Vat I. (Milk, 200 lbs.) | Vat II. (Milk, 190 lbs.; water, 10 lbs.) | Vat III. (Milk, 170 lbs.; water, 30 lbs.) |
| *Hrs.* | *m.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 | 30 | 81.7 | 81.5 | 84.0 |
| 1 | 0 | 74.1 | 75.0 | 77.5 |
| 1 | 30 | 73.1 | 72.5 | 73.7 |
| 2 | 0 | 70.5 | 70.5 | 71.7 |
| 2 | 30 | 68.9 | 69.0 | 70.3 |
| 3 | 0 | 67.2 | 67.7 | 68.2 |

Vat III contained about 4 pounds more water and less milk solids than vat I, but the curd in vat III lost moisture more rapidly than that in vat I, and in one and one-half hours after cutting the percentage of moisture content of the three curds was practically identical. The addition of 30 pounds of water to 170 pounds of milk does not notably increase the moisture content of the resulting curds. The addition of water decreases the percentage of fat, also the ratio of casein to water, but does not affect the ratio of acid to casein in the vat. It has been shown above that such variations in the percentage of fat and in the ratio of casein to water have only a very slight influence on the moisture content of the resulting curd. Although the acidity of milk is decreased by adding pure water, the ratio of acid to casein is not affected and the final moisture content of the curd is not affected by such dilution. The most marked effect produced by adding water to milk is the increased time required for coagulation with rennet before the curd can be cut.

## RATE OF MOISTURE SEPARATION FROM CURD AT VARIOUS STAGES AFTER CUTTING.

The moisture content of curds held at fixed temperatures from setting to dipping has been given in a previous experiment (see Table 4, p. 15). The weight, per 100 pounds of milk, of whey separated from the curd during successive time periods, as in vat I of the experiment referred to, can be calculated, as is shown in Table 37. For example, thirty minutes after cutting (column 1, Table 4), the curd contained 83.1 per cent moisture. As whey contains about 5 per cent of solids, the percentage of whey present may be represented by 1.05 times 83.1 per cent, or 87.2 per cent (column 3). The remaining 12.7 per cent of the curd is fat and casein, of which 100 pounds of milk contains 8.7 pounds. The fat and casein were determined respectively by the Babcock and the Hart methods. The weight of the curd was $\frac{8.7}{0.127}$ or 68.5 pounds. The weight of whey in the curd was $8.7 \times \frac{87.2}{12.7} = 59.3$ pounds (column 5). The weight of whey expelled from the cubes was $91.3 - 59.3 = 32$ pounds (column 6).

TABLE 37.—*Distribution of milk constituents between (a) curd cubes and (b) whey surrounding the cubes.*

| Time after cutting curd. | Water found in curd by analysis. | Whey present in curd (calculated). | (a) Curd cubes contain— | | (b) Whey above curd contains water, sugar, etc. |
|---|---|---|---|---|---|
| | | | Fat and casein. | Water, sugar, etc. | |
| *Hrs. m.* | *Per cent.* | *Per cent.* | *Pounds.* | *Pounds.* | *Pounds.* |
| 0 0 | 87.0 | 91.3 | 8.7 | 91.3 | 0.0 |
| 0 30 | 83.1 | 87.2 | 8.7 | 59.3 | 32.0 |
| 1 30 | 77.8 | 81.7 | 8.7 | 38.8 | 52.5 |
| 2 30 | 73.0 | 76.6 | 8.7 | 28.5 | 62.8 |
| 2 45 | 64.3 | 67.5 | 8.7 | 18.3 | 73.0 |
| 3 0 | 60.5 | 63.5 | 8.7 | 15.1 | 76.2 |
| 4 0 | 53.9 | 56.6 | 8.7 | 11.3 | 80.0 |
| 6 0 | 43.4 | 45.5 | 8.7 | 7.3 | 84.0 |
| 6 20 | 39.8 | 41.8 | 8.7 | 5.4 | 85.9 |

It is clear that in this case the weight of whey separated from the curd during the first half hour was greater than during any subsequent similar period. (See fig. 26.) It may be questioned whether, other things being equal, the rate of separation of whey from curd at any time is proportional to the whey content of the curd at that time. To determine this, calculate, as in Table 38, the average weight of whey present in the cubes (column 3) during each of the time periods, and the average of loss of whey per minute (column 4) in each period. Dividing *b* by *a* gives the loss of whey per minute per pound of whey present in the cube, as shown in the last column. (See fig. 27.)

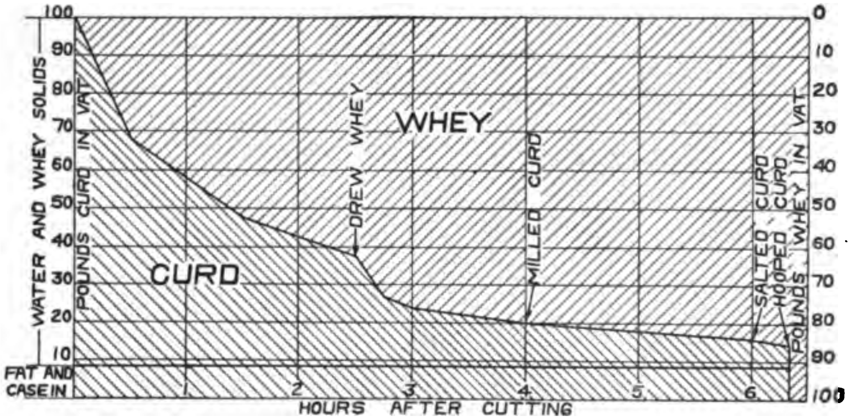

FIG. 26.—Showing the proportions of curd and whey in the vat at different stages of cheese making. Note that the rate of whey separation is accelerated at cutting, dipping, and salting.

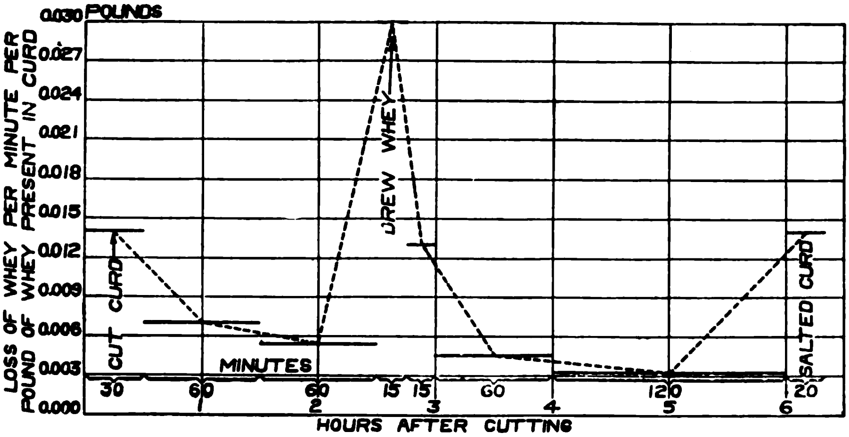

FIG. 27.—Showing the rate of loss of whey at various stages of the process. The loss occurs most rapidly at the points when the curd is cut, dipped, and salted.

**Table 38.**—*Loss of whey from curd per minute per pound of whey present in curd.*

| Time after cutting. | Length of period. | (*a*) Average weight of whey in curd cubes during period. | (*b*) Average loss per minute of whey from curd. | Loss per minute per pound of whey present. |
|---|---|---|---|---|
| *Hrs. m.* | *Hrs. m.* | *Pounds.* | *Pounds.* | *Pounds.* |
| 0 30 | 0 30 | 75.0 | 1.06 | 0.014 |
| 1 30 | 1 0 | 49.0 | .34 | .007 |
| 2 30<br>(Drew whey.) | 1 0 | 33.6 | .18 | .0054 |
| 2 45 | 0 15 | 23.4 | .70 | .030 |
| 3 0 | 0 15 | 16.7 | .21 | .013 |
| 4 0<br>(Milled.) | 1 0 | 13.2 | .06 | .0045 |
| 6 0<br>(Salted.) | 2 0 | 9.3 | .03 | .0032 |
| 6 20<br>(Hooped.) | 0 20 | 6.3 | .09 | .014 |

The loss of whey during any short period of time is not proportional to the whey content of the curd at that time. The amount lost per minute decreases much more rapidly than the whey content of the curd, showing that the less the whey content is the more tightly it is held to the curd.

The loss of moisture is more rapid during the first half hour after cutting than at any subsequent period while the curd is in the whey. The loss of moisture per minute which occurs when the curd is first put on the rack is greater in proportion to the actual moisture content of the curd than at any other period in the process. Immediately after cutting, drawing, and salting the rate of whey separation is accelerated, but rapidly falls off as time passes.

### INFLUENCE OF THE HAND RAKE AS COMPARED WITH MECHANICAL AGITATORS.

The statement has been made by cheese makers that stirring a curd in a large vat with a hand rake causes more rapid firming than the use of mechanical agitators. If this is true, the difference may be due to greater pressure applied to the curd by the rake than by the agitator, since with the rake the curd must be repeatedly stirred up from the bottom, where it has settled, while with the agitator little settling occurs. It may be also that the use of the rake breaks up curd cubes somewhat more than the agitator; in which case, of course, the smaller pieces would lose moisture faster.

Other similar questions have arisen, but their consideration will be taken up later. Many practical questions respecting the combined influence of a given set of conditions can be answered from a study of the experiments already described.

## CONCLUSIONS.

1. Variations in the proportion of rennet between 2 and 6 ounces per 1,000 pounds of milk do not influence the rate at which whey separates from curd in the cheese vat.

2. The action of rennet on milk curd for a longer or shorter period before cutting, or the relative softness or hardness of the curd when cut, does not influence the rate at which whey separates from curd.

3. During ripening the acidity of whey within curd cubes rises much faster and higher than that of the whey surrounding the cubes, because the principal seat of acid formation in the cheese vat is in the curd; whey gains most of its acidity from the curd.

4. The withdrawal of part of the whey from the vat soon after cutting does not affect the rate of separation of whey from curd, but the remaining whey rises more rapidly in acidity as a result of such withdrawal.

5. Curds made from very sweet or from overripe milk retain a larger proportion of moisture than curds from milk of medium ripeness.

6. Four curds cut with ¼, ⅜, ½, and ¾ inch curd knives, respectively, contained 49.7, 52.9, 58.2, and 69.8 per cent of moisture two and one-half hours after cutting, showing how great differences of moisture content are produced by using different knives.

7. Four curds set at 86° but heated thirty-five minutes after cutting to 86°, 92°, 98°, and 104°, respectively, contained 73.6, 63.7, 62, and 57.9 per cent of moisture two and one-half hours after cutting, showing that higher temperature facilitates the separation of whey.

8. Curds from sweet milk set at 86°, 92°, 98°, and 104° and all heated to 104° thirty-five minutes after cutting, differed in moisture content at first, but were alike after 1 hour. When ripe milk is used, one and one-half to two and one-half hours is required to reach the same end.

9. High acidity and high temperature induce rapid separation of the whey immediately after cutting. If the surface layers of the cubes are dehydrated by too rapid initial whey separation, so as to form a skin covering an interior pulp, the subsequent separation of whey is delayed. The yield of cheese is decreased, due to an excessive loss of fat through the broken curd walls, when such curds are taken out of the whey. Curds from overripe milk should be heated later and more slowly after cutting than curds from sweet milk, in order to avoid the skin-and-pulp condition, to insure complete removal of whey, and to avoid unnecessary loss of fat.

10. Pressure applied to curd in the press, on the rack, or under the whey hastens the separation of whey. On account of the buoying effect of the surrounding whey, the pressure of curd cubes on each other when allowed to settle under the whey is too slight to hasten the separation of moisture from curd. If the whey be mostly removed from the vat one-half hour before matting, so as to leave the curd under the pressure due to its own weight, whey is rapidly expelled. A little whey left in the bottom of the vat at this time helps to prevent matting.

11. When curd is piled on the rack its weight is great enough to expel moisture at an increased rate, until the moisture content reaches about 38 per cent, or until the process is stopped by matting. Stirring a curd on the rack prevents matting. When a curd is well stirred its final moisture content depends to a great extent on its acidity.

12. Variations in the fat content of milk, within ordinary limits, influence only very slightly the rate at which whey separates from curd, the presence of more fat tending to retard the process.

13. Variations in the percentage of casein or water in milk within ordinary limits have corresponding influence on the rate of moisture separation, the tendency being always toward the production of cheese with uniform moisture content. The addition of water to milk does not increase the moisture content of the resulting cheese, as the curd from watered milk gives up moisture more rapidly after cutting.

14. The loss of moisture immediately after cutting is rapid, but decreases in speed as time passes. The rate is increased when the curd is taken out of the whey and piled. After this it is rapidly decreased and is again increased when the curd is salted. The loss of moisture, per pound of moisture in the curd, is greatest at the time the curd is taken out of the whey and piled.

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# THE INFLUENCE OF LACTIC ACID ON THE QUALITY OF CHEESE OF THE CHEDDAR TYPE.

BY

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WASHINGTON:
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1910.

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# LETTER OF TRANSMITTAL.

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U. S. Department of Agriculture,
Bureau of Animal Industry,
*Washington, D. C., March 14, 1910.*

Sir: I have the honor to transmit the accompanying manuscript of an article entitled "The Influence of Lactic Acid on the Quality of Cheese of the Cheddar Type," by C. F. Doane, of the Dairy Division of this Bureau. Mr. Doane has for some time been stationed at one of the principal cheese-making centers of the country, carrying on work connected with the manufacture and storage of cheese under practical conditions. The experiments described in the present paper have resulted in establishing data which are contrary to the usual practice of factories producing the Cheddar type of cheese, and are therefore calculated to be of value to this section of the cheese-making industry. I recommend the publication of the article in the bulletin series of this Bureau.

Very respectfully,

A. D. Melvin,
*Chief of Bureau.*

Hon. James Wilson,
*Secretary of Agriculture.*

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# THE INFLUENCE OF LACTIC ACID ON THE QUALITY OF CHEESE OF THE CHEDDAR TYPE.

## INTRODUCTION.

The relation of lactic acid to the science of cheese making, particularly its action under varying conditions, and the necessity, or otherwise, for its development during the process of manufacture, are among the greatest unsolved problems connected with the dairy industry.

In the making of the Cheddar type of cheese at the present time the expert cheese maker is chiefly concerned with this development of lactic acid, and his entire ability is exerted to secure a uniformity of cooking with the development of the acid. This is desired because it is believed that a maximum quantity of acid is necessary for the best results. This maximum development is determined by the amount of acid that the curd will stand in the whey at the time of drawing the latter without subsequent injury to the texture and the color of the cheese. The best cheese makers are agreed, almost without exception, that on this development of acid depends to a great extent the delicate flavor that the best cheese should have, also, the desired closeness of body, as well as some of the qualities of texture found in the best cheese. Under the present conditions, therefore, there is ample opportunity for the exhibition of skill in handling the milk and the curd, since the attainment of even a small degree of success in securing uniformity of the different processes under varying conditions comes only with long practice and keen observation.

## LACTIC-ACID PROBLEMS IN CHEESE MAKING.

There is undoubtedly much yet to be learned concerning the development of lactic acid and its effects in cheese making. One apparent inconsistency lies in the differing effects of the lactic acid which is developed before, as compared with that which is developed after, the whey is drawn. It it well known that the development of acid in the whey beyond approximately 0.2 per cent will result in an acid cheese, although a slight variation from this will depend upon whether the milk is working fast or slow. A high-acid condition has a decidedly injurious effect on the texture and the color of the cheese, and the greater the development of acid in the whey beyond the above limit the more pronounced is the injury. On the other hand, after the whey is drawn and the curd is put on the rack, the acid may develop until the expressed whey shows a full 1 per cent, or even more, without any injury to texture or color. This would certainly appear to be inconsistent. In both cases the acid formed is evidently lactic acid. In both cases the acid is formed inside of the curd particles, as the greater part of the bacteria are carried down into the curd after setting the milk and cutting the curd,[a] and the acid is formed in the curd and expelled into the whey. We have, then, in each case a process of acid formation operating under such similar conditions as to be apparently identical, yet the results are radically different. While in the whey a development of 0.3 per cent of lactic acid will practically ruin the commercial value of the cheese, yet in the matted curd more than three times this quantity may develop with what most cheese makers believe to be a benefit, and certainly without apparent injury.

In the best present-day practice in cheese making there is an attempt to develop all the acid possible without injury to the texture and color of the product. To begin with, a maximum amount of acid is developed in the whey, and finally the curd is allowed to remain on the rack until all the acid that will develop in a practicable length of time is obtained. But while there are many positive opinions in regard to the good results of this method, there is but little accurate knowledge. The effect of acid on flavor is not known, and, contrary to general opinion, a glance at some of the tables included in this paper will show that a flat or low flavor may be found in a high-acid cheese. Again, the actual effects of a so-called proper development of acid on the closeness or the texture of the cheese is not known. The desired characteristics of texture, body, and flavor may be found, and have been found on numberless occasions, when the curd has been worked through comparatively sweet.

However, we know beyond doubt that a high acid development in the whey will injure the resulting product. Furthermore, we have very good reason to believe that a high acid development in the curd made from so-called gassy milk is necessary to overcome the gas, and it may at the same time prevent a full development of the undesirable flavors attending gassy curds.

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[a] J. L. Sammis. Factors controlling the moisture content of cheese curds. U. S. Department of Agriculture, Bureau of Animal Industry, Bulletin 122.

TABLE 1.—*Details of storage experiments showing inferiority of high-acid cheese.*

| No. of cheese. | Storage temperatures[a] and age of cheese when stored. | Numerical score. | | | | | Descriptive score. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Flavor (max. 45). | Texture (max. 30). | Color (max. 15). | Make-up (max. 10). | Total (max. 100). | Flavor. | Texture. | Color. |
| 1N2 | 32° room, at once | 21⅓ | 19⅓ | 7 | 10 | 57⅔ | Tainted, sweet | Curdy, stiff | Mottled. |
| 2N1 | Ripened in curing room | 23⅓ | 19⅓ | 11⅓ | 10 | 64 | Acid taint | Pasty, loose | Acid cut. |
| 2N2 | 32° room, at once | 22⅔ | 19⅓ | 8⅓ | 10 | 60⅓ | Sour | Stiff, gritty | Do. |
| 2N3 | 40° room, at once | 24 | 20⅔ | 9⅔ | 10 | 64⅓ | ....do | ....do | Do. |
| 3N2 | 32° room, at once | 26 | 24⅔ | 12 | 10 | 72⅔ | Fruity | Short, salvy | Do. |
| 3O2 | 32° room, 1 week | 23 | 19 | 13 | 10 | 65 | Tainted | Curdy, short | Do. |
| 4N3 | 40° room, at once | 27⅓ | 25 | 14 | 10 | 76⅓ | Fruity, flat | Salvy | Do. |
| 4O2 | 32° room, 1 week | 28⅓ | 24⅓ | 12 | 10 | 74⅔ | ....do | ....do | Do. |
| 5N2 | 32° room, at once | 37⅓ | 26⅔ | 15 | 10 | 89 | Sweet | ....do | Straight. |
| 5O2 | 32° room, 1 week | 36⅓ | 24⅓ | 15 | 10 | 85⅔ | ....do | ....do | Do. |
| 5O3 | 40° room, 1 week | 34⅔ | 22 | 15 | 10 | 81⅔ | Sweet, tainted | Mealy, loose | Acid cut. |
| 6N2 | 32° room, at once | 31 | 22 | 15 | 10 | 78 | Tainted, bitter | Salvy | |
| 6O3 | 40° room, 1 week | 35 | 24 | 15 | 10 | 84 | ....do | Smooth | |
| 7N2 | 32° room, at once | 32⅓ | 26⅚ | 15 | 10 | 84⅙ | Tainted, barn | ....do | |
| 7N3 | 40° room, at once | 32 | 26½ | 15 | 10 | 83½ | Tainted slightly | ....do | |
| 7O3 | 40° room, 1 week | 36⅔ | 26 | 15 | 10 | 87⅔ | ....do | ....do | |
| 8N2 | 32° room, at once | 33⅓ | 22½ | 15 | 10 | 80⅚ | Sweet | Gritty | |
| 8O3 | 40° room, 1 week | 31 | 24 | 15 | 10 | 80 | ....do | Weak | |
| 9N2 | 32° room, at once | 32⅔ | 21⅔ | 8⅚ | 10 | 73⅙ | Tainted, weedy | Mealy | Acid cut. |
| 9N3 | 40° room, at once | 32 | 22 | 8⅔ | 10 | 72⅔ | Bitter | ....do | Do. |
| 9O2 | 32° room, 1 week | 32 | 23⅔ | 9⅓ | 10 | 75 | Sweet, bitter | ....do | Do. |
| 10N2 | 32° room, at once | 29⅓ | 24 | 13⅓ | 10 | 76⅔ | Tainted | Short, weak | |
| 10N3 | 40° room, at once | 31⅔ | 24 | 12 | 10 | 77⅔ | ....do | ....do | |
| 10O2 | 32° room, 1 week | 30 | 22⅔ | 10⅓ | 10 | 73 | ....do | ....do | Do. |
| 11N2 | 32° room, at once | 37⅔ | 26 | 15 | 10 | 88⅔ | Weedy, flat | Coarse | |
| 11O2 | 32° room, 1 week | 37⅔ | 24 | 15 | 10 | 86⅔ | Acid taint | Gritty | |
| 11N3 | 40° room, at once | 40⅔ | 29⅓ | 14 | 10 | 94 | Flat | ....do | |
| 11O3 | 32° room, 1 week | 36⅓ | 24⅓ | 15 | 10 | 85⅔ | Cowy, weedy | ....do | |
| 12N2 | 32° room, at once | 36 | 26⅔ | 15 | 10 | 87⅔ | Sweet, cowy | Smooth | Straight. |
| 12N3 | 40° room, at once | 33⅓ | 24⅔ | 13⅓ | 10 | 81⅓ | ....do | Gritty | Acid cut. |
| 12O2 | 32° room, 1 week | 36⅓ | 25 | 15 | 10 | 86⅓ | Sweet | ....do | Do. |
| 12O3 | 40° room, 1 week | 29⅓ | 24⅔ | 13 | 10 | 77 | ....do | ....do | Do. |
| 13N2 | 32° room, at once | 30⅔ | 26 | 12½ | 10 | 79⅙ | Tainted | Smooth | |
| 13N3 | 40° room, at once | 32 | 24⅔ | 15 | 10 | 81⅔ | Tainted, cowy | Loose | |
| 13O2 | 32° room, 1 week | 33⅙ | 25½ | 13⅔ | 10 | 82⅓ | Tainted | ....do | |
| 13O3 | 40° room, 1 week | 32⅚ | 25⅚ | 15 | 10 | 83⅔ | ....do | ....do | |
| 14N2 | 32° room, at once | 30 | 25 | 15 | 10 | 80 | Tainted, flat | Tallowy | Straight. |

[a] Temperatures Fahrenheit.

TABLE 1.—*Details of storage experiments showing inferiority of high-acid cheese*—Continued.

| No. of cheese. | Storage temperature[a] and age of cheese when stored. | Numerical score. | | | | | Descriptive score. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Flavor (max. 45). | Texture (max. 30). | Color (max. 15). | Make-up (max. 10). | Total (max. 100). | Flavor. | Texture. | Color. |
| 14N3 | 40° room, at once | 28⅓ | 22⅔ | 12⅓ | 10 | 73⅓ | Tainted | Salvy, mealy | Acid cut. |
| 14O2 | 32° room, 1 week | 32⅓ | 24⅔ | 14 | 10 | 81 | do. | do. | Do. |
| 14O3 | 40° room, 1 week | 31 | 25⅓ | 14 | 10 | 80⅓ | Tainted, bitter | do. | Do. |
| 15N2 | 32° room, at once | 31 | 26 | 15 | 10 | 82 | Sweet, tainted | Weak, smooth | Straight. |
| 15N3 | 40° room, at once | 26⅓ | 25 | 15 | 10 | 76⅓ | Sweet | do. | Do. |
| 15O2 | 32° room, 1 week | 29⅓ | 27 | 11 | 10 | 77⅓ | Bitter, sweet | Weak, mealy | Acid cut. |
| 16J2 | 32° room, immediately | 31⅔ | 23⅓ | 14⅔ | 10 | 79⅔ | Tainted, flat | Weak | Straight. |
| 16J3 | 40° room, immediately | 29⅔ | 23⅔ | 14 | 10 | 77⅓ | do. | Pasty | Do. |
| 16K2 | 32° room, 4 days | 27⅔ | 22⅔ | 11⅔ | 10 | 72 | Tainted | Short | Acid cut. |
| 16K3 | 40° room, 4 days | 26⅓ | 20 | 10 | 10 | 66⅓ | Bitter, sour | Short, mealy | Do. |
| 16L2 | 32° room, 1 week | 27⅓ | 20 | 11 | 10 | 68⅓ | Tainted, sour | do. | Do. |
| 16L3 | 40° room, 1 week | 26 | 21⅓ | 11 | 10 | 68⅓ | do. | do. | Do. |
| 16M2 | 32° room, 2 weeks | 27 | 22 | 13 | 10 | 72 | do. | do. | Do. |
| 16M3 | 40° room, 2 weeks | 27⅓ | 22 | 11⅔ | 10 | 71 | do. | do. | Do. |
| 17J2 | 32° room, at once | 28⅔ | 25 | 14⅓ | 10 | 78 | Tainted | Stiff | |
| 17J3 | 40° room, at once | 29 | 21 | 10 | 10 | 70 | do. | do. | Wavy. |
| 17M3 | 40° room, 2 weeks | 26⅔ | 20⅓ | 13⅓ | 10 | 70⅓ | do. | do. | Mottled. |
| 18J2 | 32° room, at once | 35⅓ | 26 | 15 | 10 | 86⅓ | Flat | Smooth, stiff | |
| 18J3 | 40° room, at once | 35⅔ | 27⅔ | 15 | 10 | 88⅓ | Flat, sour | Smooth | |
| 18L2 | 32° room, 1 week | 35⅔ | 25⅓ | 15 | 10 | 86 | Flat | do. | |
| 18L3 | 40° room, 1 week | 34⅔ | 26 | 15 | 10 | 85⅔ | Sweet, sour | Smooth, stiff | |
| 18M3 | 40° room, 2 weeks | 32⅓ | 24⅓ | 15 | 10 | 81⅔ | Sweet, tainted | Stiff, gritty, Swiss holes | |
| 19J2 | 32° room, at once | 31⅔ | 27 | 15 | 10 | 83⅔ | Flat, low | Mechanical holes | |
| 19J3 | 40° room, at once | 31⅓ | 25⅓ | 15 | 10 | 81⅔ | Flat, tainted | Smooth, stiff | |
| 19L3 | 40° room, 1 week | 30⅓ | 23⅓ | 15 | 10 | 78⅔ | Tainted, cowy | Pasty | Acid cut. |
| 19M3 | 40° room, 2 weeks | 27⅓ | 24⅔ | 14 | 10 | 76 | Sweet, tainted | Stiff, gritty | Do. |
| 20J2 | 32° room, at once | 32 | 25⅓ | 15 | 10 | 82⅓ | Flat | Stiff | |
| 20J3 | 40° room, at once | 26 | 22⅓ | 15 | 10 | 73⅓ | Tainted | do. | |
| 20L2 | 32° room, 1 week | 27⅓ | 23 | 15 | 10 | 75⅓ | do. | do. | |
| 20M3 | 40° room, 2 weeks | 25 | 23 | 13⅓ | 10 | 71⅓ | do. | Lumpy, stiff | Do. |
| 21J2 | 32° room, at once | 35 | 27⅓ | 15 | 10 | 87⅓ | do. | Stiff | |
| 21J3 | 40° room, at once | 34⅔ | 27 | 15 | 10 | 86⅔ | Tainted, flat | | |
| 21L2 | 32° room, 1 week | 36⅔ | 26⅔ | 15 | 10 | 88⅓ | do. | Stiff, smooth | |
| 21M3 | 40° room, 2 weeks | 31 | 25⅓ | 15 | 10 | 81⅓ | do. | do. | |
| 22J2 | 32° room, at once | 36 | 27⅓ | 15 | 10 | 88⅓ | Flat | Smooth | |
| 22J3 | 40° room, at once | 34 | 26½ | 15 | 10 | 85½ | do. | Smooth, stiff | Straight. |
| 22L2 | 32° room, 1 week | 31 | 24 | 14⅓ | 10 | 79⅓ | Tainted | Mealy, stiff | Acid cut. |
| 22L3 | 40° room, 1 week | 30⅔ | 23⅔ | 12 | 10 | 76⅓ | do. | Mealy | Do. |
| 22M3 | 40° room, 2 weeks | 30⅔ | 26 | 9 | 10 | 75⅔ | do. | do. | Do. |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 23J2 | 32° room, at once | 27⅓ | 21⅓ | 13 | 10 | 71⅔ | Acid, badly tainted | do | Do. |
| 23M3 | 40° room, 2 weeks | 24 | 20 | 11 | 10 | 65 | do | do | Do. |
| 24J2 | 32° room, at once | 29⅔ | 26⅔ | 12 | 10 | 78⅓ | Acid, tainted | do | Do. |
| 24L2 | 32° room, 1 week | 29 | 23⅓ | 13 | 10 | 75⅓ | do | do | Do. |
| 24M3 | 40° room, 2 weeks | 26 | 20⅔ | 10 | 10 | 66⅔ | do | do | Do. |
| 25J2 | 32° room, at once | 29⅓ | 20⅓ | 14 | 10 | 73⅔ | Bitter, flat | do | Do. |
| 25J3 | 40° room, at once | 26 | 21 | 9 | 10 | 66 | Bitter, tainted | do | Do. |
| 25L2 | 32° room, 1 week | 26 | 20⅓ | 10 | 10 | 66⅓ | Acid, tainted | do | Do. |
| 25M3 | 40° room, 2 weeks | 22 | 18 | 8 | 10 | 58 | do | do | Do. |
| 26J2 | 32° room, at once | 34⅓ | 26⅓ | 14⅓ | 10 | 85 | Tainted, flat | Stiff, smooth | |
| 26J3 | 40° room, at once | 33 | 26⅔ | 14⅓ | 10 | 84 | Tainted | do | |
| 26K2 | 32° room, 4 days | 32⅔ | 23⅔ | 15 | 10 | 81⅓ | Tainted, flat | do | |
| 26K3 | 40° room, 4 days | 34⅔ | 24⅔ | 15 | 10 | 84⅓ | Tainted | Stiff, curdy | |
| 26L2 | 32° room, 1 week | 35⅓ | 25 | 15 | 10 | 85⅓ | do | Stiff, tough | |
| 26L3 | 40° room, 1 week | 30⅔ | 24⅔ | 15 | 10 | 80⅓ | do | Tough | |
| 26M2 | 32° room, 2 weeks | 23⅓ | 22⅓ | 15 | 10 | 70⅔ | Badly tainted | Stiff, tough | Wavy. |
| 26M3 | 40° room, 2 weeks | 29⅔ | 24 | 10⅓ | 10 | 74 | do | Stiff | Do. |
| 27J2 | 32° room, at once | 22 | 19 | 9 | 10 | 60 | Sour, tainted | Short, mealy | Acid cut. |
| 27J3 | 40° room, at once | 23⅓ | 20⅔ | 9 | 10 | 63 | do | do | Do. |
| 27K2 | 32° room, 4 days | 23⅔ | 20⅓ | 9 | 10 | 63 | do | do | Do. |
| 27K3 | 40° room, 4 days | 24⅔ | 20⅓ | 11 | 10 | 66 | do | Short | Do. |
| 27L2 | 32° room, 1 week | 25⅔ | 20⅓ | 10 | 10 | 66 | do | Short, mealy | Do. |
| 27L3 | 40° room, 1 week | 24⅔ | 19⅔ | 9 | 10 | 63⅓ | Sour, badly tainted | do | Do. |
| 27M2 | 32° room, 2 weeks | 20 | 19 | 9 | 10 | 58 | do | do | Do. |
| 27M3 | 40° room, 2 weeks | 18⅓ | 17 | 7 | 10 | 52⅓ | do | do | Do. |
| 28J2 | 32° room, at once | 28 | 23 | 11 | 10 | 72 | Sour, flat | do | Do. |
| 28J3 | 40° room, at once | 28 | 23⅔ | 12 | 10 | 73⅔ | do | do | Do. |
| 28K2 | 32° room, 4 days | 27⅔ | 22⅔ | 10 | 10 | 70⅓ | Acid | do | Do. |
| 28K3 | 40° room, 4 days | 26⅓ | 22⅔ | 10 | 10 | 69 | Acid, tainted | do | Do. |
| 28L2 | 32° room, 1 week | 26⅓ | 22⅔ | 11 | 10 | 70 | do | do | Do. |
| 28L3 | 40° room, 1 week | 27⅓ | 22⅓ | 10 | 10 | 69⅔ | do | do | Do. |
| 28M2 | 32° room, 2 weeks | 23⅓ | 21⅓ | 10 | 10 | 64⅔ | do | do | Do. |
| 28M3 | 40° room, 2 weeks | 24 | 20 | 10 | 10 | 64 | Acid, tainted, bitter | do | Do. |
| 29J2 | 32° room, at once | 28 | 24⅔ | 15 | 10 | 77⅔ | Tainted, sweet | Loose, gas holes | |
| 29J3 | 40° room, at once | 28⅔ | 25 | 15 | 10 | 78⅔ | Sweet, bitter | Gas holes | |
| 29K2 | 32° room, 4days | 25⅔ | 24⅔ | 15 | 10 | 75⅓ | Sweet, tainted | do | |
| 29K3 | 40° room, 4 days | 24⅓ | 22⅓ | 15 | 10 | 71⅔ | do | do | |
| 29L2 | 32° room, 1 week | 26⅔ | 23⅔ | 15 | 10 | 75⅓ | do | do | |
| 29L3 | 40° room, 1 week | 26⅓ | 23 | 15 | 10 | 74⅓ | do | do | |
| 29M2 | 32° room, 2 weeks | 23 | 21⅓ | 15 | 10 | 69⅓ | do | do | |
| 29M3 | 40° room, 2 weeks | 23 | 21⅓ | 15 | 10 | 69⅓ | do | do | |
| 30J2 | 32° room, at once | 33 | 27⅔ | 15 | 10 | 85⅔ | Tainted, flat | Smooth | |
| 30J3 | 40° room, at once | 31⅓ | 26⅔ | 15 | 10 | 83 | do | Stiff | |
| 30K2 | 32° room, 4 days | 29⅓ | 25 | 15 | 10 | 79⅓ | do | do | |
| 30K3 | 40° room, 4 days | 29⅓ | 26 | 15 | 10 | 80⅓ | do | do | |
| 30L2 | 32° room, 1 week | 28⅓ | 25 | 15 | 10 | 78⅓ | do | Gas holes | |
| 30L3 | 40° room, 1 week | 28⅓ | 24⅓ | 15 | 10 | 77⅔ | do | do | |
| 30M2 | 32° room, 2 weeks | 29⅔ | 24⅓ | 15 | 10 | 79 | Tainted | do | |
| 30M3 | 40° room, 2 weeks | 26 | 24 | 15 | 10 | 75 | do | do | |
| 31J2 | 32° room, at once | 33 | 26⅓ | 15 | 10 | 84⅓ | Tainted, flat | Mechanical holes | |
| 31J3 | 40° room, at once | 30⅓ | 26 | 15 | 10 | 81⅓ | do | do | |

[a] Temperatures Fahrenheit.

TABLE 1.—*Details of storage experiments showing inferiority of high-acid cheese*—Continued.

| No. of cheese. | Storage temperature[a] and age of cheese when stored. | Numerical score. | | | | | Descriptive score. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Flavor (max. 45). | Texture (max. 30). | Color (max. 15). | Make-up (max. 10). | Total (max. 100). | Flavor. | Texture. | Color. |
| 31K2 | 32° room, 4 days | 31 | 27⅓ | 15 | 10 | 83⅓ | Tainted, flat | Smooth, mechanical holes | |
| 31K3 | 40° room, 4 days | 28⅓ | 25 | 15 | 10 | 78⅓ | do | Gritty, mechanical holes | |
| 31L2 | 32° room, 1 week | 28 | 25 | 15 | 10 | 78 | do | do | |
| 31L3 | 40° room, 1 week | 26⅔ | 24⅔ | 15 | 10 | 76⅓ | do | Gritty, gas holes | |
| 31M2 | 32° room, 2 weeks | 26⅔ | 25⅔ | 15 | 10 | 77⅓ | Tainted | do | |
| 31M3 | 40° room, 2 weeks | 24⅔ | 25 | 15 | 10 | 74⅔ | do | do | |
| 32J2 | 32° room, at once | 30⅓ | 27 | 15 | 10 | 82⅓ | Tainted, flat | Gas holes, smooth | |
| 32J3 | 40° room, at once | 27⅓ | 25⅓ | 15 | 10 | 77⅔ | do | Short | |
| 32K2 | 32° room, 4 days | 27⅔ | 25⅓ | 15 | 10 | 78 | Tainted | do | |
| 32K3 | 40° room, 4 days | 26⅔ | 25 | 14 | 10 | 75⅔ | do | do | Acid cut. |
| 32L2 | 32° room, 1 week | 26 | 24⅔ | 12 | 10 | 72⅔ | do | do | Do. |
| 32L3 | 40° room, 1 week | 26⅓ | 24⅔ | 10 | 10 | 71 | do | do | Do. |
| 32M2 | 32° room, 2 weeks | 25 | 23⅔ | 10 | 10 | 68⅔ | do | do | Do. |
| 32M3 | 40° room, 2 weeks | 26⅔ | 23⅔ | 10 | 10 | 70⅓ | Tainted, bitter | do | Do. |
| 33J2 | 32° room, at once | 27 | 24 | 13 | 10 | 74 | Tainted, bitter, flat | Short, mealy | Do. |
| 33J3 | 40° room, at once | 28 | 25 | 14 | 10 | 77 | do | do | Do. |
| 33K2 | 32° room, 4 days | 25⅓ | 22⅔ | 11 | 10 | 69 | do | do | Do. |
| 33K3 | 40° room, 4 days | 24⅔ | 22⅔ | 12 | 10 | 69⅓ | Tainted, bitter | do | Do. |
| 33L2 | 32° room, 1 week | 25⅓ | 23⅔ | 10⅓ | 10 | 69⅓ | do | do | Do. |
| 33L3 | 40° room, 1 week | 26⅔ | 26 | 12⅔ | 10 | 75⅓ | Tainted, sour | do | Do. |
| 33M2 | 32° room, 2 weeks | 23⅔ | 23⅓ | 10 | 10 | 67 | do | do | Do. |
| 33M3 | 40° room, 2 weeks | 24⅔ | 23⅔ | 10⅓ | 10 | 68⅔ | do | do | Do. |
| 34J2 | 32° room, at once | 32 | 27½ | 14 | 10 | 83½ | Tainted, flat | Smooth | |
| 34J3 | 40° room, at once | 33⅓ | 27⅔ | 14 | 10 | 85 | do | do | |
| 34K2 | 32° room, 4 days | 31⅓ | 26⅓ | 14 | 10 | 81⅔ | do | do | |
| 34K3 | 40° room, 4 days | 31⅓ | 27⅔ | 14 | 10 | 83 | do | | |
| 34L2 | 32° room, 1 week | 30⅔ | 26 | 14 | 10 | 80⅔ | do | Pasty, gas holes | |
| 34L3 | 40° room, 1 week | 29 | 26 | 14 | 10 | 79 | Tainted | do | |
| 34M2 | 32° room, 2 weeks | 28⅔ | 25⅓ | 14 | 10 | 78 | do | do | |
| 34M3 | 40° room, 2 weeks | 28⅓ | 24⅔ | 14 | 10 | 77 | do | do | |

1. The cheeses which had too much acid are noted as "acid cut" in the column headed "Color."
2. The first figure in the number of the cheese indicates the lot or vat.

[a] Temperatures Fahrenheit.

## EFFECT OF HIGH ACIDITY ON QUALITY OF STORAGE CHEESE.

The attention of the writer was called to one phase of this acid question at the time of scoring the cheese in the storage experiments made in the summer of 1906. A representative of the Dairy Division visited a number of cheese factories near Plymouth, Wis., that were having trouble with their product, and secured a quantity of cheese for storage. Most of these lots of cheese turned out to be high acid, and it was noted that where this was the case the quality was so very low as to make it appear that the acid was responsible in part at least for the poor flavor, as well as for the other undesirable characteristics always found in a high-acid cheese.

The cheese in question was obtained for the purpose of determining the effect of storage on different kinds of poor cheese. It was purchased in July and August and was scored in January. The scores are given in Table 1. Because of the large proportion of this cheese that turned out to be high acid the work as planned was not satisfactory, but it did show the tendency to make high-acid cheese when troubles with bad milk are experienced, and it illustrated very well the probable effect of high acid on the quality of the product. There were 34 lots of the cheese, each consisting of 8 cheeses, one-half of which were stored in the 32° F. room at various periods ranging up to two weeks, the other half being similarly placed in the 40° F. room. The average score on flavor for the high-acid cheese was 27, while the average on the normal acid cheese was 31. The comparatively poor flavor of all the high-acid cheese was so marked that all who were connected with the scoring of this cheese noticed it and commented upon it.

The Dairy Division made some high-acid cheese in the summer of 1906 to determine the effects of storage on this quality of product. The cheese was made from exceptionally good milk, and the flavor should have been, in some of the lots at least, above criticism. Nine lots of cheese were made with varying amounts of acid. Quite a wide variation in the percentages of acid was sought, especially at the time the whey was drawn, as the degree of acidity at this period influences the quality of the cheese more than the acidity shown at any other period of its manufacture. The acid at the time of setting was regulated to suit the percentage desired at the time of drawing the whey. The percentages of acid at different stages of manufacture are shown in Table 3.

Eight cheeses were made in each lot. These were stored two at a time—one at 32° F. and the other at 40° F.—at each of the following periods: Fresh from the press, four days old, one week old, and two weeks old. All the cheese was scored by three judges working independently, and Table 2 gives the average scores. Table 4, abstracted

TABLE 2.—*Average scores of cheese, showing influence of high acid.*

| No. of cheese. | Storage temperature[a] and age of cheese when stored. | Numerical score. | | | | | Descriptive score. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Flavor (Max. 45). | Texture (Max. 30). | Color (Max. 15). | Make-up (Max. 10). | Total (Max. 100). | Flavor. | Texture. | Color. |
| 1R2 | 32° room, at once | 31⅔ | 26⅓ | 14 | 10 | 82 | Tainted, flat | Smooth | Straight. |
| 1R3 | 40° room, at once | 30 | 25⅔ | 14 | 10 | 80⅓ | Flat, acid | Gritty | Slightly acid cut. |
| 1S2 | 32° room, 4 days | 28⅔ | 24⅓ | 13 | 10 | 76 | High acid, tainted | Short, gritty | Wavy. |
| 1S3 | 40° room, 4 days | 27 | 24⅓ | 13 | 10 | 74½ | Tainted, slight acid | Stiff, gritty | Acid cut. |
| 1T2 | 32° room, 1 week | 26⅔ | 23⅔ | 12⅓ | 10 | 72½ | Acid, tainted, sweet | Crumbly, mealy | Wavy. |
| 1T3 | 40° room, 1 week | 26 | 24 | 12 | 10 | 72 | Acid, tainted | Mealy, loose | Acid cut. |
| 1U2 | 32° room, 2 weeks | 27⅓ | 24⅔ | 14 | 10 | 76 | Tainted, acid | Short, stiff | Do. |
| 1U3 | 40° room, 2 weeks | 26⅔ | 25 | 14 | 10 | 75⅔ | Sharp, acid | Stiff, gritty | Do. |
| 2R2 | 32° room, at once | 26 | 24⅓ | 12 | 10 | 72⅓ | Acid, tainted | Pasty, gritty | Do. |
| 2T2 | 32° room, 1 week | 24⅓ | 23⅓ | 10⅔ | 10 | 68⅓ | do. | Mealy, gritty | Do. |
| 2U3 | 40° room, 2 weeks | 24 | 18⅓ | 11 | 10 | 63⅓ | Acid | Short, mealy | Do. |
| 3R2 | 32° room, at once | 23⅔ | 22⅓ | 11 | 10 | 67 | Acid, tainted | Mealy, short | Do. |
| 3T2 | 32° room, 1 week | 23⅓ | 18⅓ | 9⅔ | 10 | 61⅓ | Acid | Short, mealy | Do. |
| 3U3 | 40° room, 2 weeks | 21⅓ | 17 | 7⅔ | 10 | 56 | Acid, taint | Dry, mealy | Do. |
| 4R2 | 32° room, at once | 25 | 22⅓ | 9⅔ | 10 | 67 | Acid, sour | Short, mealy | Do. |
| 4T2 | 32° room, 1 week | 22⅔ | 18 | 8 | 10 | 58⅔ | Acid, taint, sour | Dry, mealy | Do. |
| 4U3 | 40° room, 2 weeks | 22 | 18⅓ | 8 | 10 | 58⅓ | Sour, acid | do. | Do. |
| 5R2 | 32° room, at once | 20 | 14 | 5⅔ | 10 | 49⅔ | Acid, taint, sour | do. | Do. |
| 5U3 | 40° room, 2 weeks | 18⅓ | 14⅓ | 5 | 10 | 47⅔ | Acid, taint | Short, loose | Do. |
| 6R2 | 32° room, at once | 28⅔ | 25 | 11 | 10 | 74⅔ | Acid, flat | Pasty, weak | Do. |
| 6T2 | 32° room, 1 week | 26 | 24 | 10 | 10 | 70 | Acid, tainted | Short, mealy | Do. |
| 6U3 | 40° room, 2 weeks | 25 | 21⅓ | 9 | 10 | 65⅓ | do. | Mealy, gritty | Do. |
| 7R2 | 32° room, at once | 26⅔ | 25 | 11 | 10 | 72⅔ | Acid | Pasty | Do. |
| 7T2 | 32° room, 1 week | 25⅓ | 23 | 10⅓ | 10 | 68⅔ | Acid, tainted | Pasty, mealy | Do. |
| 7U3 | 40° room, 2 weeks | 26⅓ | 22⅓ | 10 | 10 | 68⅔ | Acid, taint | Mealy, gritty | Do. |
| 8R2 | 32° room, at once | 27⅔ | 23⅓ | 10⅔ | 10 | 71⅔ | Acid | Pasty, gritty | Do. |
| 8T2 | 32° room, 1 week | 27 | 24 | 10⅓ | 10 | 71⅓ | do. | Pasty, mealy | Do. |
| 8U3 | 40° room, 2 weeks | 24⅓ | 21⅓ | 12 | 10 | 67⅔ | Sour, tainted | Dry, mealy | Do. |
| 9R2 | 32° room, at once | 26⅔ | 24 | 10⅓ | 10 | 71 | Acid, tainted | Pasty | Do. |
| 9T2 | 32° room, 1 week | 25⅓ | 22 | 9 | 10 | 66⅓ | Acid, sour | Dry, mealy | Do. |
| 9U3 | 40° room, 2 weeks | 24⅓ | 21⅔ | 9 | 10 | 65 | Acid, tainted | Mealy, gritty | Do. |

The first figure indicates the lot; thus all cheeses with No. 1 came from the same vat.

[a] Temperatures Fahrenheit.

from Table 2, and figure 1 are arranged to show more clearly the relation of the numerical score to the acidity. Not all the scores are given, but those omitted are in line with those given. Enough are given to show conclusively the effect of the high acid on the cheese.

**Table 3.**—*Acidity at stated periods of high-acid cheese used in storage experiments and scored in Table 2.*

| No. of lot. | Acidity when set. | Acidity when cut. | Acidity when drawn. |
|---|---|---|---|
| | *Per cent.* | *Per cent.* | *Per cent.* |
| 1 | 0.175 | 0.120 | 0.207 |
| 2 | .175 | .......... | .229 |
| 3 | .185 | .......... | .240 |
| 4 | .195 | .......... | .215 |
| 5 | .260 | .184 | .303 |
| 6 | .200 | .145 | .225 |
| 7 | .175 | .......... | .220 |
| 8 | .182 | .......... | .211 |
| 9 | .170 | .120 | .220 |

**Table 4.**—*Relation of the numerical score to the acidity of cheese described in Table 2.*

| Number of lot. | Acidity. | 32° room, at once. | | | 32° room, one week. | | | 40° room, two weeks. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Flavor. | Texture. | Total. | Flavor. | Texture. | Total. | Flavor. | Texture. | Total. |
| | *Per ct.* | | | | | | | | | |
| 1 | 0.207 | 31⅔ | 26⅓ | 82 | 26⅔ | 23⅔ | 72⅓ | 26⅔ | 25 | 75⅔ |
| 8 | .211 | 27⅔ | 23⅓ | 71⅓ | 27 | 24 | 71⅓ | 24⅓ | 21⅓ | 67⅔ |
| 4 | .215 | 25 | 22⅓ | 67 | 22⅔ | 18 | 58⅔ | 22 | 18⅓ | 58⅓ |
| 7 | .220 | 26⅔ | 25 | 72⅔ | 25⅓ | 23 | 68⅔ | 26⅓ | 22⅓ | 68⅓ |
| 9 | .220 | 26⅔ | 24 | 71 | 25⅓ | 22 | 66⅓ | 24⅓ | 21⅔ | 65 |
| 6 | .225 | 28⅔ | 25⅓ | 74⅔ | 26 | 24 | 70 | 25 | 21⅓ | 65⅓ |
| 2 | .229 | 26⅓ | 24⅓ | 72⅓ | 24⅓ | 23⅓ | 68⅓ | 26⅔ | 18⅓ | 63⅓ |
| 3 | .240 | 23⅔ | 22⅓ | 67 | 23⅓ | 18⅓ | 61⅓ | 21⅓ | 17 | 56 |
| 5 | .303 | 20 | 14 | 49⅔ | ........ | ........ | ........ | 18⅓ | 14⅓ | 47⅔ |

It has already been stated that the above cheese was made as far as could be judged from perfect milk and that the curds worked through in excellent shape. At least a few cheeses should have been of excellent quality; but it appears that the quality was injured in about the same proportion as the amount of acid developed. The cheese in lot 1 was made with acid very slightly in excess of normal, and the cheese from this lot that was placed in the 32° room at once scored 82, while the similarly treated cheese in lot 5 was made with much too high a development of acid and scored a fraction less than 50. It is probable that cheese made from good milk would never score as low as 50 points or as low as 20 points in flavor if it had been treated normally in all stages of making and curing. Hence it would appear very probable that the high-acid development was responsible in part, at least, for the poor flavor. These results were so contrary to all belief and teaching that it was thought desirable to make some accurate comparative tests that would settle the question beyond controversy. For this purpose the author spent some time at a factory near Plymouth, Wis., and carried out the experiments described in the following pages.

## EXPERIMENTAL WORK TO TEST EFFECT OF ACID ON FLAVOR.

Sixteen lots of cheese were made for these experiments. Two lots were made each day from vats of divided milk so as to have identical conditions as regards quality of milk. One of these lots was worked up with just sufficient acid in the whey to make a light-acid cheese, the other lot being worked up on the same day in the regular way for that factory. The cheese maker in charge of this factory set his milk and drew the whey somewhat sweeter than is customary among the best cheese makers; but the curd was allowed to develop the acid on the rack until all danger of gas had passed. Table 5 shows some of the details of the manufacture of each lot.

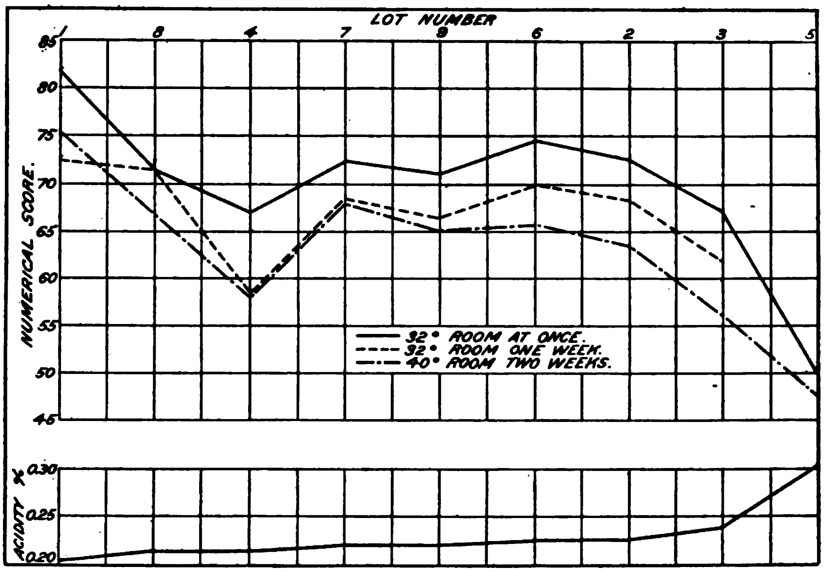

FIG. 1.—Diagram showing relation of acidity to score of cheese at various periods and temperatures.

The cheese was made during the first half of September, 1907, and each lot was held in the factory curing room one week before being placed in storage. The storage room was held at about 33° F. The cheese was scored in the middle of January, 1908, by J. W. Moore and Robert McAdam, of the Dairy Division, both experienced cheese makers and judges. The average score of each cheese is shown in Table 6, and the relation of the numerical score to the acidity is graphically shown in figure 2.

TABLE 5.—*Details of manufacture of cheese for test of high acid on flavor.*

| Lot. | Time set. | Acidity when set. | Time cut. | Time drawn. | Acidity when drawn. | Curd ground. | Curd salted. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| | *a. m.* | *Per cent.* | *a. m.* | *a. m.* | *Per cent.* | *p. m.* | *p. m.* | |
| 1, acid.... | 7.52 | 0.17 | 8.25 | 11.00 | 0.23 | 1.15 | 1.40 | Curd firm; few pin holes; bad flavor. |
| 1, sweet.. | 7.45 | .17 | 8.25 | 10.00 | .17 | 12.30 | 2.15 | Numerous pin holes; bad flavor, same as acid vat. |
| 2, acid.... | 8.30 | .20 | 8.50 | 9.55 | .20 | 12.20 | 1.30 | Good curd. |
| 2, sweet.. | 7.20 | .17 | 7.55 | 9.15 | .15 | 12.30 | 1.30 | Do. |
| 3, acid.... | 8.10 | .20 | 8.30 | 9.55 | .20 | 11.45 | 12.30 | Good curd; slight taint. |
| 3, sweet.. | 7.40 | .175 | 8.20 | 9.45 | .16 | 12.00 | 12.30 | Few pin holes; slight taint. |
| 4, acid.... | 7.50 | .20 | 8.20 | 9.35 | .21 | 12.06 | 1.00 | Gassy. |
| 4, sweet.. | 7.40 | .17 | 8.20 | 9.45 | .18 | 12.45 | 1.30 | Do. |
| 5, acid.... | 10.00 | .20 | 10.20 | 11.55 | .21 | 2.20 | 3.30 | Slight taint; pin holes. |
| 5, sweet.. | 8.50 | .17 | 8.45 | 10.40 | .16 | 1.00 | 2.30 | Do. |
| 6, acid.... | 8.40 | .20 | 9.02 | 10.45 | .20 | 1.00 | 2.15 | Do. |
| 6, sweet.. | 8.00 | .19 | 8.30 | 10.30 | .16 | 12.40 | 2.00 | Do. |
| 7, acid.... | 8.52 | .20 | 9.15 | 10.45 | .20 | 1.00 | 2.00 | Slight taint. |
| 7, sweet.. | 8.10 | .18 | 8.50 | 10.50 | .18 | 2.00 | 3.00 | Slight taint; few pin holes. |
| 8, acid.... | 9.20 | .145 | 9.40 | 11.30 | .19 | 1.30 | 2.30 | Slight taint; pin holes. |
| 8, sweet.. | 7.45 | .175 | 8.32 | 10.45 | .16 | 1.15 | 2.00 | Do. |

TABLE 6.—*Average scores of cheese described in Table 5.*

| Lot. | Numerical score. | | | | | | Descriptive score. | | |
|---|---|---|---|---|---|---|---|---|---|
| | Acidity when drawn. | Flavor (max. 45). | Texture (max. 30). | Color (max. 15). | Make-up (max. 10). | Total (max. 100). | Flavor. | Texture. | Color. |
| | *Per ct.* | | | | | | | | |
| 1, acid.... | 0.23 | 35½ | 23½ | 13½ | 10 | 82½ | Sour whey, sweet... | Coarse, mealy, stiff. | Acid cut. |
| 1, sweet... | .17 | 39 | 28 | 15 | 10 | 92 | Sweet............... | Mechanical holes... | Straight. |
| 2, acid.... | .20 | 34 | 24½ | 13¼ | 10 | 81¾ | Sour, bitter, unclean. | Short, pasty, mealy. | Acid cut. |
| 2, sweet... | .15 | 39 | 27½ | 15 | 10 | 91½ | Unclean............ | Mechanical holes... | Straight. |
| 3, acid.... | .20 | 33½ | 23 | 13¼ | 10 | 79¾ | Very unclean, sweet, sour whey. | Crumbly, mealy.... | Acid cut. |
| 3, sweet... | .16 | 39¾ | 27¼ | 15 | 10 | 92 | Trifle sweet......... | Coarse.............. | Straight. |
| 4, acid.... | .21 | 37½ | 24¾ | 13½ | 10 | 85¾ | Unclean, sweet...... | Short, mealy....... | Acid cut, slightly. |
| 4, sweet... | .18 | 39¾ | 27¾ | 15 | 10 | 92½ | Sweet............... | Coarse.............. | Straight. |
| 5, acid.... | .21 | 36 | 25 | 13¾ | 10 | 84¾ | Sour whey, bitter, sweet. | Crumbly, mealy, salvy. | Acid cut. |
| 5, sweet... | .16 | 39½ | 27 | 15 | 10 | 91½ | Slightly sweet....... | Uneven............ | Straight. |
| 6, acid.... | .20 | 34½ | 24 | 12¼ | 10 | 81¼ | Sour whey, bitter, sweet. | Mealy, soggy....... | Acid cut. |
| 6, sweet... | .16 | 38½ | 27¾ | 14¾ | 10 | 91 | Sweet............... | Uneven............ | Slightly faded. |
| 7, acid.... | .20 | 36¼ | 26½ | 14 | 10 | 86¾ | Fermented, sour whey, bitter, sweet. | Short, mealy....... | Acid cut. |
| 7, sweet... | .18 | 38¾ | 27¼ | 15 | 10 | 91 | Tainted, sweet...... | Weak.............. | Straight. |
| 8, acid.... | .19 | 36¼ | 25¾ | 14 | 10 | 86 | Sour, bitter, sweet... | Crumbly, mealy.... | Acid cut. |
| 8, sweet... | .16 | 38¾ | 28¼ | 15 | 10 | 92 | ..................... | ..................... | Straight. |

Average score on flavor of cheese made with normal acid, 39.
Average score on flavor of cheese made with high acid, 35.5.

As will be noted from Table 6, the milk was not perfect at any time during which the experimental cheese was made, neither was it very bad, and there was no difficulty in making a cheese that commanded full market price. There was a slight taint, also a few pin holes that worked out easily in the matted curd. It was perhaps unfortunate in some respects that the milk was not perfect for a few of the lots.

But the results of the experiment are so positive that it can not be considered otherwise than conclusive.

A study of the numerical and descriptive scores in Table 6 shows that high acid has a markedly injurious influence on the flavor. The bad flavors in the cheese made up sweet were in every case less pronounced than in that of the same lot which was made up acid. In addition other bad flavors appeared in the acid cheese that were not apparent in the cheese made normally. The sweet or fruity flavor that was noticed in all the cheese was more pronounced in the high acid than in the normal cheese of the same day. In five out of the eight lots a bitter flavor in the acid cheese appeared that was not noticeable in the normal cheese of the same day. A sour or old whey flavor appeared in most of the high-acid cheese.

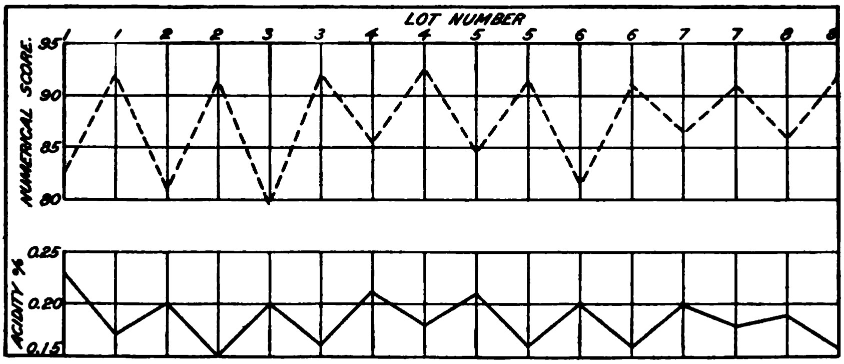

FIG. 2.—Diagram showing relation of acidity to score of high-acid and normal cheese.

## RESULTS OF EXPERIMENTS CONTRARY TO GENERAL PRACTICE.

These results are certainly very radical in view of the belief of cheese makers and the teaching of experts to the contrary. The great majority of cheese makers believe that a high development of acid is an antidote for bad flavors of all kinds, and that it is about the only means they have of fighting bad flavors as well as gas. Whenever a period of bad milk comes and the product is off flavored or gassy, the effort has always been made to develop a maximum of acid in the whey as a preventive of the trouble. It has, in fact, usually been considered advisable, where the trouble has been pronounced, to make a slightly high-acid cheese, as the high acid has been considered the less of the two evils. This practice is taught by dairy instructors and recommended by many cheese dealers who act as advisers to the cheese makers from whom they buy. The result has usually been that after a few lots of poor cheese were made at a factory a period of high-acid cheese followed. The foregoing experiments prove that this tendency to develop excessive acid is poor policy. In fact, instead of minimizing the faults it makes them more pronounced, as well as adding new faults to the product.

It is universally believed and taught that a maximum development of acid in the whey is necessary for a satisfactory and maximum development of acid in the matted curd. Dean,[a] in some of his work, seemed to show that the curd was ready for grinding and for the press at the same time regardless of the percentage of acidity at which the milk was set or the whey drawn, vats of divided milk being used for the experiments. In view of the fact that the bacteria are held within the curd particles and the acid is consequently developed in the curd, we have no reason to believe that this development would not go on as fast in the matted curd as in the whey. This would appear to be much more reasonable than the old idea that a maximum development of acid in the whey was necessary to hurry the process.

While a high acidity is needed to exclude undesirable forms of bacteria and give the cheese its desired characteristics, this high acidity can develop in the matted curd. That there is no virtue in a high development of acid in the whey can be seen from Table 5. The taint and the gas were as bad in the curd allowed to remain in the whey until a high acid was developed as they were in the curds from the comparatively sweet whey. The development of high acid in the whey did not have any effect on the growth of injurious bacteria, as far as could be judged from the product. The maximum amount of acid in the whey at time of drawing is about 0.2 per cent, and this is generally considered to be insufficient to check most of the injurious bacteria. It is the comparatively high-acid development which takes place in the matted curd that holds these bacteria in check.

From all this evidence there is but one conclusion to be drawn, namely, that the teaching which led to a maximum development of acid in the whey was wrong. The high acid developed in the whey is likely to cause much injury, and from the evidence at hand it does no good. With our present knowledge, however, it can hardly be advised to go to the other extreme and run the whey as sweet as possible, but it is certainly evident that the whey should be run sufficiently sweet to leave no possibility of making a high-acid cheese.

An interesting feature of the results of the experiments shown in Tables 1 and 2 is seen in the lots where only part of the cheese turned out to be high acid. The cheeses in those lots that were placed in storage direct from the press showed no evidence of high acid, while those that remained in the factory curing room for a time before going into storage were injured in texture and color. The point in this connection lies in the fact that the cheese that was injured in texture and color was likewise injured in flavor. Whether the low score on flavor was simply coincident with the low score on texture and color and due to the longer time that the cheese was held out of storage, or whether there is some unexplained connection between the injury in texture and the injury to flavor, might seem open to question. It would appear that the former was the case in part. If the latter be true it must be considered that the point in acidity which injures the texture also injures the flavor. There are reasons to believe that this is true, or at least that the point of acidity at which the flavor is injured and the point at which the texture is injured are not very far apart.

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[a] Twenty-second Annual Report, Ontario Agricultural College, 1896, p. 54.

There is therefore a question in connection with this which may be investigated with profit. Whey can be drawn with 0.2 per cent of acid without injury to the texture of the curd. Any acid above this evidently injures both texture and flavor. Does the injury to texture and to flavor begin at the same point in acidity, or does injury to flavor begin with a lower acidity than 0.2 per cent?

## THE USE OF STARTER IN MILK.

Nothing in this discussion should be interpreted as being opposed to the use of a good starter in the milk before setting. The development of acid is, according to our present knowledge on the subject, necessary to overcome the growth of gas-producing and other undesirable forms of bacteria. Bacteriological investigations have shown that if there is a sufficient number of lactic-acid bacteria as compared with the other kinds, the lactic-acid bacteria increase to the partial exclusion of many other kinds. When the lactic acid has developed to a relatively high degree it makes the milk or the curd an unfavorable place for many kinds of bacteria to grow. The starter can be added usually without any danger of increasing the acidity to a point where it will be difficult to cook to a proper degree of firmness before too high acidity has developed in the whey.

## EFFECT OF EARLY STORAGE ON ACID CHEESE.

This work may be considered a continuation of previous work carried on by the Dairy Division at Plymouth during the summer of 1905.[a] It was planned to determine definitely some of the results which showed incidentally in the previous work. The main point which it was desired to cover was the effect of low storage temperatures on high-acid cheese.

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[a] Bureau of Animal Industry Bulletin 85.

In the report on the previous storage work at Plymouth attention was called to the fact that in two or three lots of cheese used in the tests the cheese which was left in the factory curing room for from one to two weeks at a temperature of from 55° to 70° F. showed decidedly too much acid, almost a so-called "dead sour" in one case. The ones from the same lots (including the dead-sour lot) which went directly from the hoop into the rooms held at 32° and 40° F. were very slightly acid, in fact showed so little evidence of too much acid that the selling price was not affected in the least. This was a decidedly interesting point, and as practically all cheese dealers held entirely opposite views, a thorough demonstration of the results obtained would be of economic importance as well as of scientific value.

At the present time most of the cheese dealers protest against receiving a cheese under one week of age, because in a young cheese too much acid can not be readily detected. If it can be satisfactorily shown that a cheese which does not show too much acid at the time it goes into storage will come out of storage in good condition the objection on the part of the dealers to receiving very fresh goods would be entirely overcome, so far as high acid is concerned.

A reference to Tables 2 and 3, which give details of experiments intended to cover this point, shows that the sooner a high-acid cheese is placed in cold storage the better it is for the cheese. This is borne out by the scoring of the cheese in lot 1. The cheese that was left in the factory curing room for a week before going into storage showed decidedly acid and was badly injured, while that which went directly into storage was not injured in either texture or color. In all the other lots the scores show that the effect of the high acid was minimized by early storage.

The favorable effect that immediate storage has on high-acid cheese was very clearly demonstrated also in Table 1. Lots 4, 12, 14, 15, 16, 19, 20, 22, 26, and 31 described in this table were evidently made up with too much acid. The portions of these lots that remained in the factory curing rooms for any length of time after making showed defects in texture and color, while those that went directly into storage were not injured in the least. The average score on the high-acid lots of the cheese just referred to that went into storage at once was 78, while the average score of the lots that went into storage in one week was 74. Similarly the scores of the lots in Table 2 were 72.5 and 67.2, respectively.

In so-called dead-sour cheese early storage will minimize the damage, but it is not a cure, as is evidenced by lot 5 in Table 3. However, the buyers can usually detect these very sour cheeses at an early age, and there is no danger of deception. From these experiments it would appear that the objection on the part of the buyers to handling a cheese direct from the press is not well founded.

### CONCLUSIONS.

1. In the process of making Cheddar cheese a too high development of whey acid injures the flavor as well as the texture of the curd.
2. The development of acid in the matted curd overcomes gas and bad taints and does not injure the flavor and texture.
3. Cheese with high acid should be put into cold storage as early as possible to minimize the bad effect of the acid.

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U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF ANIMAL INDUSTRY.—BULLETIN 124.

A. D. MELVIN, CHIEF OF BUREAU.

# METHODS AND STANDARDS IN BOMB CALORIMETRY.

INVESTIGATIONS IN COOPERATION WITH THE INSTITUTE OF ANIMAL NUTRITION OF THE PENNSYLVANIA STATE COLLEGE.

BY

J. AUGUST FRIES,
*Assistant Expert in Animal Nutrition.*

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# LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
*Washington, D. C., May 5, 1910.*

Sir: I have the honor to transmit and to recommend for publication in the bulletin series of this Bureau a manuscript entitled "Methods and Standards in Bomb Calorimetry," by J. August Fries, assistant expert in animal nutrition.

The investigation described is a continuation of that already reported in Bulletin 94 of this Bureau, and is connected with the work in animal nutrition conducted at State College, Pa., by cooperation between the institute of animal nutrition of the Pennsylvania State College and this Bureau through its Animal Husbandry Division. The particular objects sought to be attained by Mr. Fries in the present paper are set forth in the accompanying letter of Doctor Armsby, the expert in direct charge of the cooperatiye investigations.

Respectfully,

A. D. Melvin,
*Chief of Bureau.*

Hon. James Wilson,
*Secretary of Agriculture.*

# LETTER OF SUBMITTAL.

STATE COLLEGE, PA., *October 20, 1909.*

SIR: I have the honor to submit herewith the results of experiments by Mr. J. August Fries, M. S., assistant expert in animal nutrition, upon "Methods and Standards in Bomb Calorimetry."

The accurate determination of the heats of combustion of organic substances is not only a fundamental requirement in the nutrition investigations now being conducted in cooperation with the institute of animal nutrition of the Pennsylvania State College, but is of great importance in many other lines of both scientific and technological research. Mr. Fries's investigations are a continuation of those reported in Bulletin 94 of the Bureau of Animal Industry and deal essentially with the standardization of methods as a means of securing results which shall be comparable among themselves and bear a definite relation to established physical constants. To this end a new method of determining the hydrothermal equivalent of the bomb calorimeter has been devised; the influence of impurities in the oxygen used, as well as of some other minor sources of error, has been studied; and a redetermination of the heat of combustion of benzoic acid has been made with reference to its acceptance as a standard substance in bomb calorimetry.

It is believed that the results of these investigations will be of interest and value to all experimenters who use the bomb calorimeter for any purpose.

Very respectfully, HENRY PRENTISS ARMSBY,
*Expert in Animal Nutrition.*

DR. A. D. MELVIN,
*Chief of the Bureau of Animal Industry.*

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# METHODS AND STANDARDS IN BOMB CALORIMETRY.

## INTRODUCTION.

The bomb calorimeter not only is coming more and more into use in research and instruction laboratories, but has also found large practical application in fuel-testing laboratories, and is beginning to find a place of usefulness as a method of chemical analysis. With this increase in bomb-calorimeter work, and consequently increased publication of results, one fact has been brought out very clearly, namely, that there is at present great lack of uniformity in the work. Reports of the work done in these various kinds of laboratories, by differently trained men using different types of bomb calorimeters, seem to indicate that calorimetry, instead of becoming more perfected and reliable by wider application, is in a sense becoming more chaotic. One man's work can not readily be compared with that of another. A calorie, in other words, is not a definite fixed quantity, as it should be in bomb-calorimeter work, since no two persons necessarily agree concerning what standard to use.

### HYDROTHERMAL EQUIVALENT OF THE CALORIMETER.

Each individual bomb calorimeter must have its hydrothermal equivalent, or water value, determined; that is, the number of calories required to raise the mass of water and metal one degree Centigrade. Preferably, this should be done at the place where it is to be used, and by the individual who is to be responsible for the work. For this purpose it is customary to burn substances—like benzoic acid, naphthalin, camphor, cellulose, sugar, etc.—of known chemical composition, which as a rule burn readily, can easily be obtained in a high state of purity, and whose heats of combustion are supposed to be known. As to the choice of a substance against which to standardize the apparatus, however, the investigators or operators do not agree, each selecting according to his own fancy and convenience, or as influenced by some one else. Thus, some may use several substances while others choose only one. One set of analysts use naphthalin and give it a heat value of 9,628 calories per gram, while others using the same substance give it a heat value of 9,696 calories per gram. Some use benzoic acid, accepting 6,322 calories per gram as its heat of combustion value, while others regard this as too low, and use 6,335 or some other number of calories as the correct value for the standard on which their work is based. Such cases could be multiplied. Each man for himself, apparently, is the condition.

### NECESSITY OF A COMMON STANDARD.

Now, if work of this nature is to reach its greatest usefulness—that is, if the work of each individual is to be relied upon to mean a definite thing and thus be of use to everybody else interested in the same line of work—then we need above all things one common standard. The writer believes that it is high time that some single substance be chosen, a heat value agreed upon, and that substance in some way recognized as a standard for bomb-calorimeter work. In the future, should the heat value of such a substance have to be slightly changed, results would still be useful and comparable after a little calculation.

From his own personal experience with the substances mentioned, the writer believes that benzoic acid meets the requirements for a standard better than any of the other substances, and considers it the most suitable that could be selected for such a standard. It was, therefore, for the purpose of calling attention to existing conditions and with the hope of perchance being able to do something which should help to bring to pass in the near future the adoption of such a standard that a redetermination of the heat of combustion of benzoic acid was undertaken.

The plan of the undertaking was to determine again the heat of combustion of benzoic acid, independently of all previous determinations of the heat of combustion of any organic substance whatsoever, using an improved bomb calorimeter recently described.[a] The problem itself, which it was desired to work out step by step, with reference to the material and apparatus on hand, can be stated as follows:

Having a new bomb calorimeter of unknown hydrothermal equivalent, or water value, also an oxygen supply of undetermined correction for any combustible gases which may be present as impurity, and assuming that no organic substance exists which has had its heat of combustion accurately determined so as to be referred to or accepted as a standard; to determine the heat of combustion of benzoic acid.

### DETERMINATION OF THE WATER VALUE OF THE BOMB CALORIMETER.

The first requirement in order to solve the problem before us is to determine the water equivalent of the whole bomb-calorimeter system, assuming also that no substance with a known heat of combustion value was to be had. In order to determine this water value of the apparatus two known methods, one of which at least is frequently referred to in connection with the bomb calorimeter, were used, and also a third method devised by the writer.

---

[a] The Journal of the American Chemical Society, Vol. XXI, p. 272, 1909.

### BY COMPUTATION OF COMPONENT PARTS.

The first and more commonly used of the two known methods consists in computing from the weight of each of the component parts of the bomb system and the corresponding specific heats the water value of each substance, the sum of all giving the water equivalent of the whole system or apparatus. This method is not necessarily absolutely correct, since the weight of some of the parts can only be known approximately, as, for instance, the glass and mercury of the thermometer, small rubber pieces, etc., which can not be disconnected or weighed. Further, the specific heat of the particular steel used for the bomb itself has not been determined, nor is it certain that the other specific heats are all absolutely correct. However, while we can not claim absolute correctness for this method, the total value obtained for the whole system, including the water, need not vary more than a few hundredths, or at most a very few tenths, of 1 per cent from the true water value.

The apparatus in question was an Atwater-Hempel bomb calorimeter, having the top modified so as to permit the determination of the carbon dioxid after a combustion. The modification consists in having, besides the usual valve and opening for the intake of oxygen, an outlet terminating in a platinum tube near the bottom of the bomb and through which the gases are removed for analysis.

From the weight of each of its different parts and their respective specific heats, the following water value for the bomb calorimeter system was obtained:

TABLE 1.—*Computed water value of bomb calorimeter.*

| Material. | Weight. | Specific heats. | Water equivalent. |
|---|---|---|---|
| | *Grams.* | | *Grams.* |
| Steel | 3,236.0 | [a] 0.1114 | 360.49 |
| Platinum | 196.0 | [a] .0320 | 6.27 |
| Lead | 66.0 | [a] .0300 | 1.98 |
| German silver (approximate) | 4.0 | [a] .0940 | 0.38 |
| Rubber (approximate) | 4.0 | [b] .3310 | 1.32 |
| Iron (approximate) | 10.0 | [a] .1114 | 1.11 |
| Mercury (approximate) | 50.0 | [a] .0330 | 1.65 |
| Glass (approximate) | 10.0 | [a] .1900 | 1.90 |
| Britannia metal | 855.0 | [a] .0548 | 46.85 |
| Oxygen (constant volume) | 11.4 | [a] .1570 | 1.79 |
| Water at 22° C | 2,000.0 | [c] .9975 | 1,995.00 |
| Total | | | 2,418.74 |

[a] The Journal of the American Chemical Society. Vol. XXV, p. 694. 1903.
[b] H. W. Wiley. Principles and Practice of Agricultural Analysis. Vol. III, p. 573. 1897.
[c] Annalen der Physik. ser. 4, **16**, 616 (1905.)

Except in the cases of rubber and water, the specific heats used in the above computation are those used by Atwater in determining the water value of his bomb calorimeter. For the small quantity of iron in the connectors the same specific heat is used as for the steel. The specific heat of water is the average result of Dieterici and Barnes's determinations.

According to Table 1, the total water equivalent of the whole bomb-calorimeter system, including the water, is 2,418.74, or without the water it is 423.74. Should the other value given by Atwater for steel (0.1087 specific heat) be used, the water equivalent would be 415, or 2,410 including the water. The water in which the bomb is immersed and through which the heat is measured should always be the same in amount in order to insure the same water level in the cylinder, thus keeping the conditions unchanged. With this apparatus 2,000 grams of water will immerse the bomb completely, and is the quantity which was uniformly employed.

### THE ELECTRIC METHOD.

The second method employed in determining the water equivalent consisted in generating a measured amount of heat in the bomb by means of an electric current passing through a resistance coil. The generation of heat in the bomb and the measurement of the rise in temperature due to it were done under the same conditions as when a substance is burned for its energy determination, except that no oxygen was introduced into the bomb. Correction, therefore, must be made for the usual amount of oxygen in computing the results.

The test was made in the following manner: About 10 inches of size 26 B. & S. = 0.016 "nichrome" resistance wire was made into a small coil which was connected to the two platinum wires in the bomb in such a manner that the heat would be generated at about the same place as where the substances analyzed are burned. The resistance of this wire coil was about 1.38 ohms. Next, the bomb was closed, placed in the water, and connected up as for a determination of heat of combustion, and the two insulated copper wires leading from the bomb were connected to the electrical instrument. The electric current was supplied by six storage cells and was measured by voltmeter and ammeter. After starting the stirrer and taking the usual few minutes preliminary readings of the water temperatures, the switch was closed at a given signal and the current from the six cells sent through the bomb. It was allowed to flow through for a number of minutes, the readings of the voltmeter and ammeter being taken every half minute. The water temperature was taken every minute by means of a Beckman thermometer read to 0.001° C. During the first few trials the voltmeter and ammeter used were the commercial, so-called American, instruments, the ammeter having an external shunt.

The various observations noted during one of these trials in which the electric current was on continuously for 12 minutes are found in Table 2.

TABLE 2.—*Electric determination of water equivalent.*

| Period. | Time. | Temperature of calorimeter. |  | Voltmeter. | Ammeter. |
|---|---|---|---|---|---|
|  |  | As read. | Corrected. |  |  |
|  | *Minutes.* | ° *C.* | ° *C.* | *Volts.* | *Amperes.* |
| Preliminary | 1.0 | 1.236 | 1.2432 |  |  |
|  | 2.0 | 1.239 |  |  |  |
|  | 3.0 | 1.244 |  |  |  |
|  | 4.0 | 1.247 |  |  |  |
|  | 5.0 | 1.252 | 1.2592 |  |  |
| Current on | 5.5 |  |  | 11.68 | 4.62 |
|  | 6.0 | 1.370 | 1.3781 | 11.62 | 4.60 |
|  | 6.5 |  |  | 11.60 | 4.60 |
|  | 7.0 | 1.660 | 1.6696 | 11.60 | 4.60 |
|  | 7.5 |  |  | 11.59 | 4.58 |
|  | 8.0 | 1.970 | 1.9807 | 11.59 | 4.58 |
|  | 8.5 |  |  | 11.58 | 4.58 |
|  | 9.0 | 2.280 | 2.2918 | 11.58 | 4.58 |
|  | 9.5 |  |  | 11.58 | 4.60 |
|  | 10.0 | 2.595 | 2.6084 | 11.58 | 4.60 |
|  | 10.5 |  |  | 11.58 | 4.60 |
|  | 11.0 | 2.910 | 2.9240 | 11.58 | 4.60 |
|  | 11.5 |  |  | 11.58 | 4.60 |
|  | 12.0 | 3.225 | 3.2385 | 11.58 | 4.60 |
|  | 12.5 |  |  | 11.58 | 4.60 |
|  | 13.0 | 3.545 | 3.5567 | 11.58 | 4.60 |
|  | 13.5 |  |  | 11.58 | 4.60 |
|  | 14.0 | 3.845 | 3.8564 | 11.58 | 4.60 |
|  | 14.5 |  |  | 11.58 | 4.60 |
|  | 15.0 | 4.155 | 4.1667 | 11.58 | 4.60 |
|  | 15.5 |  |  | 11.58 | 4.60 |
|  | 16.0 | 4.470 | 4.4816 | 11.58 | 4.60 |
|  | 16.5 |  |  | 11.58 | 4.60 |
|  | 17.0 | 4.780 | 4.7914 | 11.58 | 4.60 |
| Equalizing | 18.0 | 4.974 | 4.9860 |  |  |
|  | 19.0 | 5.005 | 5.0170 |  |  |
|  | 20.0 | 5.008 | 5.0200 |  |  |
|  | 21.0 | 5.009 | 5.0210 |  |  |
| End period | 22.0 | 5.006 |  |  |  |
|  | 23.0 | 5.004 |  |  |  |
|  | 24.0 | 5.001 |  |  |  |
|  | 25.0 | 4.998 | 5.0100 |  |  |

The ammeter used had an initial correction of 0.16, which has to be added to the average of the readings. Accordingly, the average for the current was:

For total time, 11.588 volts, 4.757 amperes; for last 8 minutes, 11.58 volts, 4.76 amperes.

Room temperature, 24° C.

Temperature of water at beginning, 21.2° C.

Temperature of water at end, 25.0° C

Most of the figures found in the second column of Table 2 were read when the mercury column in the thermometer was moving rather fast, hence a ± error of one or two thousandths of a degree could readily be made, but any error of that kind is reduced to a minimum by the number of readings taken. If we examine the table, we notice that from about the third minute there was a uniform increase in temperature of the bomb system, while the voltmeter and ammeter remained unchanged, indicating a constant current. Because of this constancy, as regards both the current and the rise in temperature of the calorimeter, the results of the test can be worked out either from the total rise in temperature and total heat generated, or from a section of the time consisting of the last 8 or 9 minutes.

The radiation correction, or correction due to the influence of the surrounding air conditions, in the case of the electric tests, as well as in all the following determinations of heats of combustion, has been worked out by using the Regnault-Pfaundler formula[a]—

$$\frac{v-v'}{t'-t}\left(\sum_1^{n-1}\theta r+\frac{\theta n+\theta_1}{2}-nt\right)-(n-1)v=\Sigma\Delta t$$

$\sum_1^{n-1}\theta r$ = sum of readings minus 1 increased by an arbitrary factor $\frac{\theta_2-\theta_1}{9}$

$v$ = average rate of radiation during preliminary period.

$v'$ = average rate of radiation during end period.

$\theta n$ = number of readings during combustion period.

$t$ = average of preliminary thermometer readings.

$t'$ = average of end period thermometer readings.

Applying the correction thus found to the entire test represented by Table 2, we have:

| | °C |
|---|---|
| Last reading of the heating period | +5.0210 |
| First reading of the heating period | −1.2592 |
| Radiation correction | − .0029 |
| Correction for thermometer lag | − .0010 |
| Total rise in temperature | 3.7579 |

If we take a section consisting of the last 8 minutes of the test, and represent by means of a curve the gain and loss to the system by radiation, we obtain a correction of +0.0013° C. and a correction for thermometer lag of −0.0005° C. Applying these corrections to the last 8 minutes, we have:

| | °C |
|---|---|
| Thermometer reading for the twelfth minute | +4.7914 |
| Thermometer reading for the fourth minute | −2.2918 |
| Radiation correction | + .0013 |
| Correction for thermometer lag | − .0005 |
| Corrected rise for 8 minutes | 2.5004 |

In computing the heat generated in the bomb by the electric current and the corresponding water equivalent of the apparatus the mean small calorie is used, that is, one one-hundredth of the heat required to heat 1 gram of water from 0° to 100° C., equivalent to 4.1834 Joules.[a] The electrical energy developed in the bomb and measured as heat would then be expressed in calories by the following formula:

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[a] H. W. Wiley. Principles and Practice of Agricultural Analysis. 1897. Vol. III, p. 572.

$$\text{Calories} = \frac{\text{volts} \times \text{amperes} \times \text{seconds}}{4.1834}$$

During the 12 minutes, or 720 seconds, we had the following amount of heat evolved in the bomb:

$11.588 \times 4.757 \times 720 \div 4.1834 = 9{,}487.4$ calories,

and

$9{,}487.4$ calories $\div 3.7579°$ rise $= 2{,}524.7$ grams water equivalent.

At the time of the test there was no oxygen in the bomb; hence a correction for the amount usually present in the bomb must be applied. The amount of oxygen in this bomb at 20 atmospheres pressure equals 10.24 grams, which, multiplied by 0.157—the specific heat of oxygen at constant volume—equals 1.6 grams water, which must be added to the results found for the whole system, giving $2{,}524.7 + 1.6 = 2{,}526.3$ grams as the water equivalent.

For the 8-minute section referred to we have:

$11.580 \times 4.76 \times 480 \div 4.1834 = 6{,}324.5$ calories,

and

$6{,}324.5 \div 2.5004 = 2{,}529.3$ grams. Adding 1.6 for the oxygen to it gives a water equivalent of 2,530.9.

Two other tests with the same instruments were made, one having the current on for 10 minutes and the other for 12 minutes, and worked out in the manner already described, the results of the three tests being given in Table 3 below.

TABLE 3.—*Water equivalent of calorimeter by three electric tests.*

| Test. | *Time.* | Heat evolved in the bomb. | Corrected rise in temperature. | Water equivalent. | Correction for $O_2$. | Water equivalent corrected. |
|---|---|---|---|---|---|---|
| | | *Calories.* | °*C.* | *Grams.* | *Grams.* | *Grams.* |
| 1 | Total 12 minutes | 9,487.4 | 3.7579 | 2,524.7 | 1.6 | 2,526.3 |
| | Last 8 minutes | 6,324.5 | 2.5004 | 2,529.3 | 1.6 | 2,530.9 |
| 2 | Total 10 minutes | 7,969.6 | 3.1374 | 2,540.1 | 1.6 | 2,541.7 |
| | Last 6 minutes | 4,759.2 | 1.8885 | 2,520.1 | 1.6 | 2,521.7 |
| 3 | Total 12 minutes | 9,486.9 | 3.7603 | 2,522.9 | 1.6 | 2,524.5 |
| | Last 8 minutes | 6,313.0 | 2.4910 | 2,534.3 | 1.6 | 2,535.9 |

The average water value of the three tests obtained when the total heat is used is equivalent to 2,530.8 grams of water, and when the effect of the last 8 and 6 minutes of the electric current is considered, the average water value is equal to 2,529.5 grams.

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[a] A. W. Smith. Monthly Weather Review for October, 1907, p. 11.

These results are about 4.6 per cent higher than that calculated from the weights and specific heats of the material of the bomb. Among themselves, the results agree fairly well, an indication that the source of error, if any exists, must be a constant one. Suspicion fell upon the ammeter, which already had an initial error of +0.16 ampere, and the possibility of electrolytic action upon the water. Another ammeter was used, this time a Weston instrument, and a piece of rubber tubing was slipped over the metal connector so as to have no metal in direct contact with the water. Two tests were made under these conditions, the electric current being on for 12 minutes in each case.

Without reproducing the readings of the instruments, etc., the total heat as well as the heat evolved in the bomb during the last 9 minutes, the corresponding rise in temperature, and the water equivalent of the bomb system are shown in Table 4.

TABLE 4.—*Water equivalent of calorimeter by two electric tests.*

| Test. | | Heat evolved in the bomb. | Corrected rise in temperature. | Water equivalent. | Correction for $O_2$. | Water equivalent corrected. |
|---|---|---|---|---|---|---|
| | *Time.* | *Calories.* | *°C.* | *Grams.* | *Grams.* | *Grams.* |
| 1 | Total 12 minutes | 9,125.5 | 3.6985 | 2,467.3 | 1.6 | 2,468.9 |
| | Last 9 minutes | 6,828.7 | 2.7550 | 2,478.6 | 1.6 | 2,480.2 |
| 2 | Total 12 minutes | 9,066.1 | 3.6710 | 2,469.6 | 1.6 | 2,471.2 |
| | Last 9 minutes | 6,790.5 | 2,7445 | 2,474.2 | 1.6 | 2,475.8 |

With instruments of this kind where the hundredth part of an ampere or volt has to be estimated it can not be claimed nor expected that the results should be reliable to within ±0.5 per cent. The average of the above water equivalents equals 2,474 grams, which is still over 2 per cent above that computed from the specific heats. It was therefore decided to test one more possible source of error, viz, the evaporation of water from the system under the existing laboratory conditions.

### ERROR DUE TO EVAPORATION OF WATER.

The evaporation from the surface of the water in the cylinder containing the bomb is held to be of so little consequence that it is generally entirely neglected, but the writer made a few tests in order to get results which should apply to this apparatus, locality, and laboratory. In the Atwater-Hempel bomb calorimeter the water cylinder is surrounded by two separate dead-air spaces, and the two covers for these spaces are of smooth hard rubber. These covers fit snugly, so that practically there can be no currents in the inclosed air.

The tests were made in the following manner: The water cylinder was filled with water to the same level as when the bomb is in place. The stirrer was placed in the water, and to represent the two rubber-covered connecting wires for the electric current, two similar small pieces of rubber-covered wire were suspended from the edge of the vessel dipping into the water. The cylinder was then weighed to 0.01 gram and the exact time noted. It was then quickly put in its place and the stirrer operated as during a combustion for from 15 to 30 minutes. The time of starting and stopping the stirrer, as well as the time of weighing, was noted.

These evaporation tests were carried on in the calorimeter both with the stirrer in operation and with the stirrer standing undisturbed, but covered. The water was also left standing exposed to the air of the laboratory in a place where there was no draft. Standing exposed in the laboratory, the average of several trials was 0.0193 gram of water evaporated per minute, whereas standing covered in the bomb calorimeter the evaporation was only 0.0034 gram per minute. When the stirrer was in operation, the evaporation increased. Below are given the details of one of the trials:

TABLE 5.—*Evaporation of water from calorimeter.*

| Items. | Time. | Weight of vessel + water, stirrer, etc. |
|---|---|---|
| | | *Grams.* |
| Stirrer started | 9.40 a. m. | |
| Stirrer stopped | 10. 10 a. m. | |
| Difference | 30 minutes | |
| Weight before taken | 9. 38 a. m. | 3.600.56 |
| Weight after taken | 10. 13 a. m. | 3,600. 12 |
| Difference | 35 minutes | .44 |

Temperature of room, 21° C.
Temperature of water, 21° C.
Time of stirring the water, 30 minutes.
Time required for handling, 5 minutes.
Correction for 5 minutes, $5\times0.0193=0.097$ gram $H_2O$.
$0.44-0.097=0.343$ gram evaporated during 30 minutes, or 0.0114 gram per minute.

Ten trials showed the following rates of evaporation per minute:

| | Gram. |
|---|---|
| No. 1 | 0. 0067 |
| No. 2 | .0113 |
| No. 3 | .0075 |
| No. 4 | .0122 |
| No. 5 | .0114 |
| No. 6 | .0085 |
| No. 7 | .0107 |
| No. 8 | .0044 |
| No. 9 | .0048 |
| No. 10 | .0075 |
| Average | .0085 |

These tests were made between November 30 and January 17.

The above evaporation, though small, makes a correction which should not be neglected, especially when small charges are used, or charges in any way differing from the quantity used in the standardization of the apparatus. The heat of water at 21° C. is, according to Prof. A. W. Smith,[a] equal to 585.26 mean calories for 1 gram of water.

. If we apply the above correction to the last-mentioned electric tests (Table 4) it would be 16[b] minutes × 0.008 gram $H_2O = 0.128$ gram $H_2O$ and $0.128 \times 585.26 = 74.93$ calories to be subtracted from the calories given in the first column opposite the total for 12 minutes. For the 9 minutes section the correction would be $9 \times 0.008 = 0.072$ gram $H_2O$, and $0.072 \times 585.26 = 42.14$ calories. Recalculating, the four water values would be:

2, 447. 09
2, 463. 36
2, 449. 24
2, 458. 87

Average=2, 454. 64

This corrected average water value is still over 1.3 per cent greater than that computed according to the first method, and the difference is undoubtedly too large to be ascribed to the manipulation or reading of the instrument. In all probability some electrolysis of water must have taken place in spite of the precaution taken, and we can not be sure on this point, since the connection was not dry. Any error due to condensation of moisture on the outside of the water vessel, and subsequent evaporation of the same, has not been observed and can at best be but small.

The evaporation tests may throw some light upon this problem of condensation, etc. The inner air space or layer of air which surrounds the water cylinder in the calorimeter equals about 4 liters. At 22° C. these 4 liters of air when saturated would contain 0.0772 gram of water. In about 9 minutes, therefore, perfectly dry air should become fully saturated and the evaporation cease. This is not the case. The tests showed that the evaporation continued unchecked, and in the particular test already referred to there was a loss of 0.343 gram of water in 30 minutes, enough water to saturate 17.8 liters of dry air. But since the air in the calorimeter laboratory always contains some moisture, in reality a much larger volume of air would be saturated. The fiber envelope is supposed to be waterproof, and hence it is very unlikely that the water vapor is absorbed. It would seem that the water vapor which is produced at the surface of the water, near the cover, escapes to the outside by means of its own pressure through the openings in and around the cover. This unchecked evaporation and free escape of the vapor seems to indicate that the inclosed air need not necessarily be affected much, except at the very top, and that the air layer around the water cylinder is slowly changed by diffusion and convection currents.

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[a] Physical Review, Vol. XXV, No. 3, Sept., 1907, p. 170.

[b] This refers to the total time influenced by the evaporation of water when the total heat generated during the full time of 12 minutes is considered.

A direct test, by a wet and a dry bulb thermometer, which were 6.0° C. apart when standing quietly in the laboratory, showed that there was no effect whatever upon the moisture conditions in the air space during 10 minutes' operation of the bomb. These thermometers, bulbs one-third down in the space, stood 3.0° C. apart and remained so; hence there could be no condensation of moisture on the sides of the vessel.

If, now, the water cylinder as it is placed in position is a little (say 0.5 to 1° C.) colder than the air surrounding it, and the air is saturated with moisture, condensation would begin, but the conditions in the bomb room have never at the time of making a combustion been such that a condensation would have taken place at the start with only one degree difference in temperature. The water cylinder is in the calorimeter only a few minutes, as a rule, before the substance is ignited, and it is questionable if in that length of time the conditions of the air have changed enough so that a condensation can take place, except, perhaps, at the upper rim of the vessel. In less than a minute after ignition, the temperature of the water is higher than that of the surrounding air, and hence evaporation of any water which had been condensed on the vessel before the ignition took place would begin. Whether any condensation or evaporation does take place has not been experimentally demonstrated, but from the very nature of the existing conditions at this place, errors due to them may be assumed to be entirely negligible.

As a check on these evaporation results, on a clear bright day a special test was made as follows: The water cylinder, filled with water to within one-half inch of the top, was placed in position in the calorimeter container, as during an energy determination, but without the stirrer. The covers were put on as before and the cylinder was allowed to stand for 20 minutes. It was taken out and reweighed quickly, and put back the second time for 20 minutes. After that it was allowed to stand in the laboratory for 24 minutes before being weighed, another weight being taken 8 minutes later. During this laboratory test the windows and doors were closed so that there was no draft to influence the evaporation. Next, a piece of paraffined paper was fitted over the top of the water cylinder and sealed by means of melted soft wax. The cylinder was weighed and put in position in the calorimeter container as before and reweighed after 20 minutes. After that it was allowed to stand in the laboratory and was weighed after different intervals. The results are as given in Table 6.

TABLE 6.—*Evaporation tests.*

| Method. | Water cylinder. | | | Evaporation per minute. | |
|---|---|---|---|---|---|
| | Time weighed. | Weight. | Time placed in position and removed. | In laboratory. | In bomb room. |
| CYLINDER UNCOVERED. | | *Grams.* | | *Gram* $H_2O$. | *Gram* $H_2O$. |
| Bomb room, first trial | 9.14 a. m.<br>9.36½ a. m. | 3,480.43<br>3,480.32 | 9.15 a. m.<br>9.35 a. m. | | |
| Difference | 22½ mins. | .11 | 20 mins. | | |
| Bomb room, second trial | 9.36½ a. m.<br>9.58 a. m. | 3,480.32<br>3,480.21 | 9.37¼ a. m.<br>9.57¼ a. m. | | |
| Difference | 21½ mins. | .11 | 20 mins. | | |
| Average | ........ | ........ | ........ | ........ | 0.0035 |
| Laboratory, first trial | 9.58 a. m.<br>10.22 a. m. | 3,480.21<br>3,479.71 | ........ | | |
| Difference | 24 mins. | .50 | ........ | | |
| Laboratory, second trial | 10.22 a. m.<br>10.30 a. m. | 3,479.71<br>3,479.58 | ........ | | |
| Difference | 8 mins. | .13 | ........ | | |
| Average | ........ | ........ | ........ | 0.0197 | |
| CYLINDER SEALED. | | | | | |
| Bomb room | 10.37 a. m.<br>10.59 a. m. | 3,483.86<br>3,483.86 | ........ | | |
| Difference | 22 mins. | 0.00 | ........ | 0.0000 | |
| Laboratory, first trial | 10.59 a. m.<br>11.29 a. m. | 3,483.86<br>3,483.86 | ........ | | |
| Difference | 30 mins. | 0.00 | ........ | | |
| Laboratory, second trial | 11.29 a. m.<br>2.46 p. m. | 3,483.86<br>3,483.87 | ........ | | |
| Difference | 197 mins. | +.01 | ........ | | |
| Average | ........ | ........ | ........ | ........ | 0.0000 |

From this test we see that the change in weight of the water cylinder in the previous tests was due entirely to evaporation from the surface of the liquid water, and that there was no condensation on the sides of the cylinder or evaporation of any condensed moisture. During the test the temperature of the bomb room was 24° C., and the wet-bulb thermometer (having the bulb surrounded by a piece of moistened filter paper and swung back and forth) registered 16° C. The temperature of the water was 24° C., and in the laboratory the dry thermometer registered 26.5° C., and the wet-bulb thermometer 16° C.

The water equivalent of the bomb as determined by the electrical tests which have been described is not satisfactory, but the tests have, nevertheless, been useful and seem to justify the following conclusions:

1. The tendency of the electric method is to give results that are too high.
2. There are many chances for error connected with an electric test, even if the instruments used have been carefully calibrated.
3. Instruments which can be read to the hundredth part of an ampere and volt only by estimation are not accurate enough for the best work.
4. There is a possibility of electrolysis of water; hence the connection to the one wire in the bomb should not only be insulated from the metal of the bomb, but thoroughly insulated from the water surrounding the bomb as well.
5. The tests led to a more thorough investigation of the error due to evaporation of water during a bomb combustion, showing that under usual laboratory conditions there is an error which must be taken into account, at least when less or more heat is generated in the bomb than was generated at the time of its standardization.

## A THIRD METHOD.

The uncertainty of the foregoing results prompted the working out of a simple and perfectly reliable method for the determination of the water equivalent of the calorimeter.

The principle of this method consists in burning equal charges of a substance in the bomb, first, under exactly the same conditions as when a heat determination is made, and, secondly, after having, without changing any of the external conditions, such as level of water, etc., reduced the water equivalent of the system. The same amount of oxygen is used in each case. From the difference in rise of temperature and the difference in water equivalent it is possible to determine very accurately the water value of the calorimeter.

By this method it is possible, first, to use a substance of unknown or only approximately known heat of combustion and an oxygen supply of unknown purity to determine the water equivalent of the apparatus, and then by means of this new water equivalent and the same determinations to work out accurately the heat of combustion of the substance used, and also to determine the correction for impurities in the oxygen, if any such were present.

### DISPLACEMENT OF WATER.

When the bomb and stirrer are in position in the water cylinder, there is a space above the bomb and one near the bottom where part of the water can be displaced, and thereby the water equivalent of the system reduced. The displacement of water was effected by two double-walled metal rings. The one to fit above the bomb was made of sheet lead heavy enough to rest securely by its own weight. The one for near the bottom of the bomb was made of sheet zinc and was held in position by the bomb itself, hence it could be lighter than the water displaced. These rings were so made that they did not touch the sides of the water cylinder or in any way interfere with the operation of the stirrer or the thorough mixing of the water. The upper and heavier ring contained 553.5 grams of lead and solder and 25.8 grams of zinc, and had a displacement of 306 grams of water. The lower ring contained 86 grams of zinc and 20.9 grams of solder and had a displacement of 162 grams of water.

The computed water equivalent of the metal rings was:

| | |
|---|---|
| Lead (+solder) 574.4 grams $\times 0.0315$ sp. heat[a] | =18.09 |
| Zinc 111.8 grams $\times 0.0956$ sp. heat[a] | =10.68 |
| Total | 28.77 |

During a heat of combustion determination the bomb is immersed in 2,000 grams of water, which covers the highest point of the bomb to a certain depth. When the metal rings were used, a quantity of 1,532 grams of water brought the water level to this same height. To these 1,532 grams of water must be added the 28.8 grams water equivalent of the metal. Thus we have a difference of 2,000 grams $-1,560.8=439.2$ grams of $H_2O$, or $439.2\times0.99745=438.1$, in the water equivalent of the calorimeter at 22.12° C., the temperature at which the determinations of water value were made, without changing any of the other conditions. If, now, exactly equal weights of a substance and fuse wire are burned, that is, if the same amount of heat is generated in the bomb while it is immersed in the two different quantities of water, there will be a difference in the rise of temperature, and we have the necessary factors for the computation of the water value.

It is, however, a tedious and difficult manipulation to press and weigh out to the accuracy of 0.0001 gram a charge of dry, and perhaps hygroscopic material, and it is much more convenient and just as accurate to weigh out approximately equal quantities of the substance for each charge, and then, by one or the other of the two methods of calculation to be described, to compute the water equivalent of the apparatus.

In the following table (Table 7) are shown the results of a number of combustions of about equal charges of benzoic acid made under the two conditions, representing a difference of 439.2 grams of water, equal to 438.1 grams water equivalent of the system at 22° C.

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[a] Beilage zum Chemiker Kalender, 1904.

TABLE 7.—*Rise in temperature due to burning like quantities of benzoic acid in the bomb, with 20 atmospheres oxygen pressure, but with varying amounts of water in the apparatus, there being a difference of 439.2 grams of water equal to 438.1 water equivalent.*

| Water used. | Benzoic acid burned. | Fuse wire. | $HNO_3$ formed. | Rise in temperature (not corrected for evaporation or impurities in oxygen). | Rise in temperature due to wire and $HNO_3$. | Rise due to benzoic acid. | Rise due to 1 gram of benzoic acid. |
|---|---|---|---|---|---|---|---|
| *Grams.* | *Gram.* | *Calories.* | *Calories.* | ° *C.* | ° *C.* | ° *C.* | ° *C.* |
| 2,000 | 0.7157 | 26.24 | 7.10 | 1.8837 | 0.01378 | 1.86992 | 2.61272 |
| 2,000 | .7341 | 22.88 | 7.20 | 1.9293 | .01244 | 1.91686 | 2.61117 |
| 2,000 | .7034 | 26.24 | 6.90 | 1.8476 | .01370 | 1.83390 | 2.60719 |
| 2,000 | .7162 | 23.04 | 6.95 | 1.8826 | .01240 | 1.87020 | 2.61128 |
| 2,000 | .7110 | 26.56 | 6.95 | 1.8726 | .01386 | 1.85874 | 2.61426 |
| 2,000 | .7045 | 23.68 | 6.95 | 1.8510 | .01266 | 1.83834 | 2.60943 |
| Average |  |  |  |  |  |  | 2.61101 |
| 1,560.8 | .7122 | 26.24 | 8.25 | 2.2937 | .01741 | 2.27629 | 3.19614 |
| 1,560.8 | .6990 | 26.24 | 7.15 | 2.2467 | .01686 | 2.22984 | 3.19004 |
| 1,560.8 | .7031 | 26.24 | 7.40 | 2.2606 | .01698 | 2.24362 | 3.19104 |
| 1,560.8 | .7028 | 26.24 | 7.85 | 2.2524 | .01721 | 2.23519 | 3.18041 |
| Average |  |  |  |  |  |  | 3.18941 |

Difference in rise of temperature, 0.57840° C.

### WATER VALUE OF THE CALORIMETER.

Two methods can be employed to compute the water equivalent of the apparatus from the above determinations.

One method is to make use of the approximate heat of combustion value of benzoic acid, compute the total heat generated by each charge, the fuse wire, and the nitric acid, and from the average difference in rise of temperature due to a given difference in the water equivalent of the calorimeter to compute the water equivalent of the apparatus. The approximate heat of combustion value of the substance burned is computed from the combustions made under normal conditions, using the computed water value for the calorimeter, i. e., 2,418.74 grams. The approximate heat of combustion of benzoic acid computed in this way would be 6,315.3 calories per gram.

The second method consists in finding the value of the number of calories represented by the fuse wire and the nitric acid of each charge in terms of degrees rise in temperature, subtracting this from the observed rise in temperature, and then expressing the rise in temperature as per gram substance burned. The water equivalent of the apparatus is calculated from the average difference in the rise of temperature per gram and the difference between the two water equivalents. This method of computing is perhaps preferable to the former, and since the corrections for the wire and the nitric acid are small at best, it may be more correct in case there should be much variation in the size of the charges used for combustion. In Table 7 the rise per 1 gram of the substance has been obtained according to this method. To find the rise of temperature of the calorimeter due to the burning of the wire and formation of $HNO_3$, we use the calculated water equivalent of the apparatus, viz, 2,418.74 grams and 1,980.64 grams, respectively. Taking as an example the first determination in Table 7, we have:

$$2{,}418.74 : (26.24+7.10) : : 1 : X$$

$$X=0.01378^\circ \text{ C.}$$

From Table 7 we learn that 1 gram of the substance (in this case benzoic acid) burned under the normal conditions caused a rise in temperature equal to 2.61101° C. and burned when the water equivalent was reduced by 438.1 grams, caused a rise in temperature of 3.18941° C., the difference being 0.57840° C.

Letting $X$ = water equivalent of the bomb calorimeter, we have

$$2.61101\ X=3.18941\ (X-438.1 \text{ grams})$$

$$X=2{,}415.77 \text{ grams.}$$

Computed according to the first method, the water value of the bomb calorimeter would be 2,415.74 grams, which is practically identical with the foregoing, and 2,415.77 is considered as being the correct water equivalent of this calorimeter and will be used in all computations. It is, of course, the water value at 22.12° C., corresponding to a specific heat of water of 0.99745 (compare p. 20), expressed in terms of mean calories, i. e., of water at specific heat 1.0. It will be seen that this agrees very closely with the value computed from the weights and specific heats of the materials of the calorimeter; hence the latter value used in computing the rise of temperature due to the combustion of the fuse wire and of nitrogen can have introduced no appreciable error.

### CORRECTION FOR COMBUSTIBLE GASES IN THE OXYGEN.

Having the water value of the apparatus established, the next step is to test the oxygen supply for impurities in the form of combustible gases, etc. This is very important, for there is in this country at the present time, at least so far as the writer knows, no perfectly pure oxygen put up under high pressure for bomb-calorimeter use, and hence a correction must be worked out for the oxygen used, when accurate work is required. The problem may be established by two different methods:

First, by noting the influence of varying pressure of oxygen upon the combustibility of the gases when the same amount of heat is generated in the bomb during the several combustions.

Secondly, by noting the effect of varying charges, that is, the varying amounts of heat evolved, upon the combustion of the different gases, the oxygen pressure in the bomb being the same.

Analyzed by the copper oxid combustion method, the writer's associate, Mr. Braman, found the oxygen at hand to contain 0.0161 per cent of carbon and 0.0194 per cent of hydrogen by weight, and the question is: Does a part, or all, of these gaseous impurities burn during an energy determination, and, if burned, what will be the rise in temperature caused by the burning?

This bomb charged with 20 atmospheres of oxygen would, according to the above analyses, contain 0.001648 gram of carbon and 0.001986 gram of hydrogen. The ratio of carbon to hydrogen is such that they can not form any one gas, for even should all the carbon be present as methan, there would still be 0.00144 gram of free hydrogen, which alone represents about 50 calories.

It was decided to burn as large a charge of benzoic acid as would possibly burn completely in 10 atmospheres of oxygen, and then burn the same amount in 20 atmospheres; also to burn about half the quantity of the substance in oxygen of the pressures just mentioned. The final results of these tests we desire to express in terms of the quantity of heat generated in the bomb and its effect upon the impurities in the oxygen instead of in terms of any particular substance. But for our immediate purpose, we can express the rise in temperature in terms of the amount of charge used, and hence in the computation of the results we can make use of the newly found water equivalent and follow the same method employed in finding the rise in temperature per gram of substance in Table 7.

Tables 8 and 9 contain the results of two series of combustions of like charges of benzoic acid burned in different amounts of oxygen and the rise in temperature due to the impurities in the oxygen. In the first series of combustions the charges were twice the size of those in the second series. The carbon present in the form of $CO_2$ in the bomb after a combustion was determined in some instances in the case of the large charges of benzoic acid, and the average of three determinations where 20 atmospheres of oxygen were used was 68.801 per cent of carbon, the theoretical being 68.83 per cent of carbon. The three determinations with the smaller amount of oxygen gave an average of 68.713 per cent of carbon, a difference of about 0.09 per cent. This is an indication that the charges were a little too large, so that with 10 atmospheres of oxygen the combustions can not be relied upon as being complete. Assuming that this small difference in carbon represents the actual difference between complete and incomplete combustion of the benzoic acid, which can not be far wrong, we have a correction which can be applied to the rise in temperature obtained with 10 atmospheres of oxygen.

**TABLE 8.**—*Rise in temperature caused by burning like quantities of benzoic acid in varying amounts of oxygen. Results corrected for 0.032 gram water evaporation.*

| Oxygen pressure. | Benzoic acid burned. | Fuse wire. | HNO$_3$ formed. | Rise in temperature.[a] | Rise in temperature due to wire and HNO$_3$. | Rise in temperature due to benzoic acid. | Rise due to 0.7142 gram benzoic acid. |
|---|---|---|---|---|---|---|---|
| *Atmospheres.* | *Gram.* | *Calories.* | *Calories.* | °*C.* | °*C.* | °*C.* | °*C.* |
| 20 | 0.7157 | 26.24 | 7.10 | 1.8915 | 0.01380 | 1.87770 | 1.87377 |
| 20 | .7341 | 22.88 | 7.20 | 1.9371 | .01246 | 1.92464 | 1.87247 |
| 20 | .7034 | 26.24 | 6.90 | 1.8554 | .01372 | 1.84168 | 1.86996 |
| 20 | .7162 | 23.04 | 6.95 | 1.8904 | .01242 | 1.87798 | 1.87274 |
| 20 | .7110 | 26.56 | 6.95 | 1.8804 | .01388 | 1.86652 | 1.87492 |
| 20 | .7045 | 23.68 | 6.95 | 1.8588 | .01268 | 1.84612 | 1.87154 |
| Average |  |  |  |  |  |  | 1.87257 |
| 10 | .7108 | 27.04 | 1.73 | 1.8708 | .01191 | 1.85889 | 1.86778 |
| 10 | .7134 | 23.36 | 1.73 | 1.8752 | .01039 | 1.86481 | 1.86690 |
| 10 | .7112 | 21.12 | 1.73 | 1.8615 | .00946 | 1.85204 | 1.85985 |
| Average |  |  |  |  |  |  | 1.86484 |

[a] Corrected for evaporation and for difference in water value of calorimeter due to differences in amount of oxygen used.

0.7142 gram benzoic acid in 20 atmospheres O$_2$ .......... 1.87257 °C. rise.
.7142 gram benzoic acid in 10 atmospheres O$_2$ .......... 1.86484 °C. rise.
.09 per cent incomplete combustion in 10 atmospheres O$_2$ .......... .00168 °C. rise.

Difference due to 10 atmospheres oxygen .......... .00605 °C.

**TABLE 9.**—*Rise in temperature caused by burning like quantities of benzoic acid in varying amounts of oxygen. Results corrected for 0.032 gram water evaporation.*

| Oxygen pressure. | Benzoic acid burned. | Fuse wire. | HNO$_3$ formed. | Rise in temperature corrected for evaporation and variation in bomb water value. | Rise in temperature due to wire and HNO$_3$. | Rise in temperature due to benzoic acid. | Rise due to 0.3566 gram benzoic acid. |
|---|---|---|---|---|---|---|---|
| *Atmospheres.* | *Gram.* | *Calories.* | *Calories.* | °*C.* | °*C.* | °*C.* | °*C.* |
| 20 | 0.3648 | 22.88 | 3.40 | 0.9696 | 0.01088 | 0.95872 | 0.93717 |
| 20 | .3579 | 21.44 | 3.40 | .9508 | .01028 | .94052 | 0.93710 |
| Average |  |  |  |  |  |  | .93714 |
| 10 | .3595 | 23.04 | 1.03 | .95245 | .01000 | .94245 | .93484 |
| 10 | .6301 | 22.88 | 1.03 | .95215 | .00990 | .94225 | .93309 |
| 10 | .3585 | 25.76 | 1.03 | .95315 | .01109 | .94206 | .93707 |
| 10 | .3484 | 26.24 | 1.03 | .92385 | .01129 | .91256 | .93404 |
| Average |  |  |  |  |  |  | .93476 |

0.3566 gram benzoic acid in 20 atmospheres O$_2$ .......... 0.93714 °C. rise.
.3566 gram benzoic acid in 10 atmospheres O$_2$ .......... .93476 °C. rise.

Difference due to 10 atmospheres O$_2$ .......... .00238 °C.
Difference due to 15 atmospheres O$_2$ .......... .00357 °C.

The smaller charges (Table 9) were completely burned in 10 atmospheres of oxygen, which was proved by the carbon dioxid determination after the combustion giving 68.838 per cent of carbon. From the above tables we learn that there was a greater rise in temperature when the combustion took place in oxygen at high pressure than when less oxygen was present. In the case of the smaller charges, that is, less heat evolution, the difference in rise of temperature was less for each atmosphere difference in pressure than in the case of the greater heat. It is difficult to remove the last traces of a combustible gas from a gas mixture by combustion or electric sparks, and we can not expect that all combustible gases present in the oxygen would be burned in the bomb by a single combustion of any kind of substance. Further, it is to be expected that conditions may be reached relative to dilution of gases, rate of combustion of the substance, and heat evolution when the dilute gases escape combustion altogether. In the case of the 0.7142 gram of benzoic acid burned in 10 atmospheres oxygen pressure, the combustion of the substance was, as stated, not quite complete, that is, vapors or combustible gases from the burning material itself had begun to be left unburned. Hence the point when the combustible gases present in the oxygen supply will practically cease to be affected can not be far either way from 10 atmospheres oxygen pressure, with the larger charge of benzoic acid.

In order to compare the effect of the 0.3566-gram charges upon the combustible gases with that of the larger ones, the resulting rises in temperature are computed to the same basis and are given in Table 10.

TABLE 10.—*Comparison of average results obtained by burning unlike quantities of benzoic acid in like amounts of oxygen.*

| Oxygen. | Benzoic acid charges. | Average rise in temperature. | Rise computed on basis of 0.7142 gram charge. |
|---|---|---|---|
| *Atmospheres.* | *Gram.* | *° C.* | *° C.* |
| 20 | 0.7142 | 1.87257 | 1.87257 |
| 20 | .3566 | .93714 | 1.87691 |
| Difference.. | ............ | .............. | + .00434 |
| 10 | .7142 | 1.86484 | 1.86652 |
| 10 | .3566 | .93476 | 1.87214 |
| Difference.. | ............ | .............. | + .00562 |

Here we notice, first, that the smaller charges show a relatively larger rise in temperature both at 10 and at 20 atmospheres; furthermore, the small charges, which burned completely at 10 atmospheres oxygen pressure, show a greater increase over the large charges at 10 atmospheres than over the same when burned at 20 atmospheres oxygen pressure. This is an indication that the limit for combustion of the gases in the oxygen has not been reached at 10 atmospheres with a small charge. With 0.3566 gram charge, therefore, we can well assume that at 5 atmospheres oxygen pressure the conditions for burning correspond to those at 10 atmospheres with 0.7142 gram charge, i. e., twice the amount, and that, therefore, at 5 atmospheres oxygen the effect upon the combustible gases would have ceased.

Hence, the difference in rise of temperature due to combustible gases present in the oxygen supply when 0.7142 gram benzoic acid is burned in the bomb at 20 atmospheres can be represented by 0.0060° C. as found in Table 8, and for 0.3566 gram charge at 20 atmospheres oxygen 0.0036° C. (Table 9); for other amounts of benzoic acid burned the error due to combustible gases is found by interpolation.

### NATURE OF COMBUSTIBLE GASES.

As to the nature of the gas or gases which cause the rise in temperature, we know from the $CO_2$ determinations that none of the carbon in the oxygen was oxidized, and there remains, therefore, only the free hydrogen, even a portion of which is sufficient to cause the observed rise.

### THE HEAT OF COMBUSTION OF BENZOIC ACID.

We now have the correct water equivalent of the calorimeter, a correction for the impurities in the oxygen, and also the evaporation correction, and can proceed to the computation of the heat of combustion of benzoic acid.

In all the determinations the Regnault-Pfaundler formula, referred to earlier in connection with the water value determination by means of electricity, has been used for working out the radiation correction; that is, the correction for the influence of the surrounding air upon the readings. The computation of one of the determinations is given below in detail as an example, and following that will be found tabulated the results of various determinations representing a wide range of conditions, both in regard to quantity of substance burned and oxygen used. It is a satisfactory check upon the accuracy of the bomb work when very different amounts of material are burned and concordant results are obtained.

*Example of a determination of heat combustion.*

Substance, benzoic acid, Kahlbaum's.
Charge, 0.7157 gram.
Iron fuse wire completely burned, 0.0164 gram=26.24 calories.
Oxygen pressure, 20 atmospheres.
Room temperature, 23° C.
Water temperature before ignition, 21.26° C.
$HNO_3$ formed and titrated=7.10 calories.
Ignition of charge, instantaneous.
Combustion of substance, complete.
Carbon dioxid found after combustion=68.801 per cent carbon.

| | | | | | |
|---|---|---|---|---|---|
| Thermometer readings, preliminary | 1.438; | 1.440; | 1.442; | 1.444; | 1.445. |
| Thermometer readings, corrected | 1.4468; | | | | 1.4538. |
| Combustion period readings | 1.445; | 2.920; | 3.292; | 3.316; | 3.317. |
| Combustion period readings, corrected | 1.4538; | 2.9343; | 3.3058; | 3.3297; | 3.3307. |
| Thermometer readings, end period | 3.317; | 3.313; | 3.311; | 3.309; | 3.308. |
| Thermometer readings, end period, corrected | 3.3307; | | | | 3.3208. |

$v=0.0018°$ C.
$t=1.4503°$ C.
$\theta=5$
$v=-0.0025°$ C.
$t=\ 3.3258°$ C.
Thermometer lag$=-0.0005°$ C.

$$\frac{0.0018-(-0.0025)}{3.3258-1.4503}(11.1959+2.3922-7.2515)-0.0072=+0.0073$$

$$\Sigma \Delta t=+0.0073° \text{ C.}$$

| | ° C. |
|---|---|
| Last reading of combustion period | +3.3307 |
| First reading of combustion period | −1.4538 |
| Radiation correction | + .0073 |
| Correction for thermometer lag | − .0005 |
| Correction for impurities in oxygen | − .0060 |
| Evaporation of water during 4 minutes | + .0078 |
| Corrected rise in temperature | 1.8855 |

| | Calories. |
|---|---|
| Water value of bomb system with 20 atmospheres oxygen (2415.8) ×1.8855° C | 4,554.99 |
| Correction for fuse wire | −26.24 |
| Correction for $HNO_3$ | − 7.10 |
| | 4,521.65 |

4521.65÷0.7157=6317.80 calories per gram benzoic acid.

In like manner all the results found in the following table are worked out:

TABLE 11.—*Heat generated when different quantities of benzoic acid are burned in varying amounts of oxygen, and the heat of combustion per gram of benzoic acid.*

| Oxygen pressure. | Benzoic acid burned. | Fuse wire. | $HNO_3$ formed. | Observed rise in temperature. | Corrected rise in temperature. | Total heat generated in the bomb. | Heat per gram benzoic acid. | Temperature of water before ignition. |
|---|---|---|---|---|---|---|---|---|
| *Atmospheres.* | *Gram.* | *Calories.* | *Calories.* | ° *C.* | ° *C.* | *Calories.* | *Calories.* | ° *C.* |
| 25 | 0.7088 | 23.36 | 8.25 | 1.8635 | 1.8655 | 4,506.75 | 6,313.68 | 21.3 |
| 20 | .7157 | 26.24 | 7.10 | 1.8769 | 1.8855 | 4,554.99 | 6,317.67 | 21.3 |
| 20 | .7341 | 22.88 | 7.20 | 1.9288 | 1.9311 | 4,665.15 | 6,313.96 | 20.8 |
| 20 | .7034 | 26.24 | 6.90 | 1.8408 | 1.8494 | 4,467.79 | 6,304.73 | 20.7 |
| 20 | .7162 | 23.04 | 6.95 | 1.8804 | 1.8844 | 4,552.34 | 6,314.37 | 21.4 |
| 20 | .7110 | 26.56 | 6.95 | 1.8653 | 1.8744 | 4,528.18 | 6,321.62 | 20.9 |
| 20 | .7045 | 23.68 | 6.95 | 1.8435 | 1.8528 | 4,476.00 | 6,309.97 | 21.3 |
| 15 | .7160 | 26.24 | 4.40 | 1.8448 | 1.86735 | 4,511.15 | 6,310.58 | 20.4 |
| 20 | .3648 | 22.88 | 3.40 | .9591 | .9660 | 2,333.67 | 6,325.07 | 20.4 |
| 20 | .3579 | 21.44 | 3.40 | .9411 | .9472 | 2,288.25 | 6,324.13 | 20.3 |
| 10 | .3595 | 23.04 | 1.03 | .9431 | .95125 | 2,298.03 | 6,325.33 | 19.8 |
| 10 | .3601 | 22.88 | 1.03 | .9427 | .95095 | 2,297.31 | 6,313.24 | 19.9 |
| 10 | .3585 | 25.76 | 1.03 | .9390 | .95195 | 2,299.73 | 6,340.13 | 20.5 |
| 10 | .3484 | 26.24 | 1.03 | .9095 | .92265 | 2,228.95 | 6,319.38 | 20.7 |
| Average. . . | . . . . . . . . . . | . . . . . . . . . . | . . . . . . . . . . | . . . . . . . . . . | . . . . . . . . . . | . . . . . . . . . . | 6,318.12 | 20.7 |

In the above table representing fourteen determinations made under such varied conditions the results agree very well; for if we leave out the two extreme results the greatest difference from the average in the remaining twelve determinations is but 8.15 calories. Computed by the usual formula, the probable error of the mean of the fourteen determinations is ±1.51 calories and the probable error of a single determination ±5.69 calories.

### SULPHUR, PHOSPHORUS, AND CHLORIN.

The writer sometime ago[a] called attention to the fact that the acid found in the bomb after a combustion is not always $HNO_3$ alone, and that it is especially the S in organic combination, which goes over into gaseous $SO_3$ and eventually into $H_2SO_4$, that needs to be considered. Hence the sulphuric, phosphoric, and hydrochloric acids are determined when found in sufficient quantities, and the total acidity found by titration is correspondingly corrected in computing the heat arising from the oxidation of free nitrogen. Determinations of sulphur and phosphorus have been successfully carried on in feeds, feces, and urines by the bomb method during these last three years in this laboratory. In the two samples of benzoic acid which were used in the above determinations, one, Kahlbaum's best, gave no test for Cl. and only a light trace of $SO_3$. The other sample, "Merck," gave but a small trace of $SO_3$ and a distinct trace of Cl., but in no case enough to be determined for the sake of correction.

### CORRECTION FOR THE SPECIFIC HEAT OF WATER.

Since the specific heat of water differs at different temperatures, the water equivalent of the calorimeter will also vary with the temperature. In the above case the water equivalent was determined with an average of 21.08° C. water temperature before the combustions and an average of 23.15° after the combustions. The mean specific heat between these temperatures is 0.99745. The mean specific heat between the average temperatures before and after combustions in the fourteen determinations of Table 11 is 0.99752.

The true average heat of combustion, therefore, is

$$6{,}318.12 \times \frac{99752}{99745} = 6{,}318.56 \text{ calories.}^{b}$$

### CHANGE IN THE BOMB CONTENTS.

There are at least two other conditions which should be considered, since they may to some small degree influence the heat of combustion as computed from the determinations already described and recorded in Table 11.

One is a possible change in the water value of the calorimeter which may be caused by the combustion of the substance in the bomb. According to the nature of the substance, the contents of the bomb will change more or less, so as to make the water equivalent after the combustion different from what it was before.

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[a] U. S. Department of Agriculture, Bureau of Animal Industry Bulletin 94, p. 32.

[b] This method of computation assumes, of course, that the specific heats of the materials of the calorimeter itself vary with the temperature at the same rate as does that of water. The total correction is so small, however, that any error thus introduced must be insignificant.

When the same kind of material is burned as that which was used for the determination of the water value of the bomb, the changes need not be considered except when a different quantity is burned. Should an entirely different compound be burned, even if in a quantity like that used for water value determinations, the condition existing in the bomb before and after combustion should be computed whenever it is possible to do so, in order to determine whether enough change took place in the water equivalent of the bomb to call for a correction. In the computations we use the following values:

Volume of gas in bomb at 20 atmospheres, measured at 20° C., 730 mm. pressure,[a] is 8 liters.

| | Grams. |
|---|---|
| Weight per liter $O_2$ at 20°, 730 mm | 1.2798 |
| Specific heat $O_2$, constant volume | .157 |
| Specific heat, $CO_2$, constant volume | .149 |
| Specific heat benzoic acid, computed | .30 |
| Specific heat $Fe_3O_4$ | .167 |
| Specific heat $Fe_2$ | .1114 |
| Specific heat $HNO_3$ | .445 |
| Specific heat $H_2O$ | 1.0000 |

The average of 10 charges used in the water value determinations equals 0.7102 gram benzoic acid, and considering all the gas as oxygen we have in the bomb before the combustion the following water equivalent:

| | Grams $H_2O$. |
|---|---|
| Benzoic acid, 0.7102 gram $\times$ 0.30 | 0.2131 |
| Oxygen, $8\times1.2798\times0.157$ | 1.6074 |
| Iron wire, $0.0164\times0.1114$ | .0018 |
| Total | 1.8223 |

After the combustion there are in the bomb the following substances:

| | Grams. |
|---|---|
| Carbon dioxid, $0.7102\times2.5246$ | 1.7930 |
| Water, $0.7102\times0.4426$ | .3143 |
| $Fe_3O_4$, $0.0164\times1.381$ | .0227 |
| Oxygen, $10.2384-1.4309$ | 8.8075 |
| $N_2O_5$ | .0275 |

This is equivalent to the following amounts of $H_2O$:

| | Grams $H_2O$. |
|---|---|
| 1.7930 grams $CO_2\times0.149$ | 0.2672 |
| .3143 gram $H_2O\times1.000$ | .3143 |
| .0227 gram $Fe_3O_4\times0.167$ | .0039 |
| .0321 gram $HNO_3\times0.445-0.0046$ | .0097 |
| 8.8075 grams $O_2\times0.157$ | 1.3828 |
| Total | 1.9779 |

Thus with benzoic acid there is a change of only about 0.16 gram water equivalent caused by the combustion.

---

[a] Average for this locality.

If instead of benzoic acid, 0.7 gram of ethyl alcohol were burned, we should find a difference of about 0.39 gram water equivalent caused by the combustion and about 0.44 gram water equivalent different from that obtained by benzoic acid. The average charge in the fourteen determinations of Table 11 equals 0.5609 gram, and the average charge used in standardizing the bomb was 0.7102 gram, which is equivalent to a difference of 0.08 gram in the water value of the bomb, or a correction of −0.20 calorie per gram in the average result. This is a very small correction and usually need not be considered at all.

### CHANGE OF PRESSURE IN THE BOMB.

The second condition referred to above is the change in pressure in the bomb resulting from the combustion. By the heat of combustion of a substance is generally understood the heat at constant pressure, which is in many instances slightly different from that determined by the bomb calorimeter at constant volume. Since it is the difference between the conditions before and after the combustion which is considered, it makes no difference what pressure the gases may be under in the bomb before the combustion. If the pressure of the gases before and after the combustion remains the same, the heat of combustion at constant volume and constant pressure is the same. Leaving out of account the small changes due to the oxidation of iron and the formation of nitric acid in the bomb, this is theoretically true of carbohydrates where $CO_2$ and $O_2$ replace each other volume for volume. With other substances it may be different. At constant pressure compounds containing much hydrogen will cause a decrease in volume of the gases and hence require a plus correction, and compounds with less hydrogen but plenty of nitrogen may cause an increase in gas volume, and consequently there will be a minus correction to the results obtained by the bomb.

For a solid or liquid substance of the composition $C_nH_pO_q$ burned at constant volume in the bomb the heat at constant pressure is expressed by the following formula:[a]

$$CtP = CtV + 0.5424\left(\frac{\frac{1}{2}p-q}{2}\right) + 0.002\left(\frac{\frac{1}{2}p-q}{2}\right)t$$

where

$t$ = temperature.

$p$ and $q$ = number of atoms in the molecule.

According to this formula, benzoic acid, $C_7H_6O_2$, at constant pressure will be:

$$CtP = CtV + 0.5424 \times \frac{3-2}{2} + 0.002 \times \frac{3-2}{2} \times 22.8^\circ$$

which expressed in calories per gram equals:

6,318.56 + 2.41 = 6,320.97 per gram benzoic acid.

---

[a] Beilage zum Chemiker-Kalender, 1904, p. 144.

If to this we apply the correction found for the change in the bomb content because of unlike charges, −0.20 calorie, the heat of combustion of 1 gram benzoic acid, $C_7H_6O_2$, at constant pressure will be: 6,320.77±1.51 mean calories, a value practically identical with that found by Stohman, viz, 6,322 calories.

## USE OF THE BOMB CALORIMETER UNDER DIFFERENT CONDITIONS.

Judging from these investigations, there are many conditions which may influence the work with the bomb and cause the results to become inaccurate, and the question is, What is the best and most convenient way to operate the bomb so as to get reliable results under the various conditions? Three methods in regard to the determination of the water value of the calorimeter and its use may be employed according to existing laboratory and other conditions:

1. The apparent water value may be directly determined by burning a given weight of a standard substance, note being taken of all the conditions existing at the time of standardization of the bomb, including amount of substance and of oxygen, and atmospheric conditions influencing evaporation. If, now, the substance to be analyzed corresponds in quantity to the calories generated at the standardization, and if the other conditions are the same, there will be no corrections to apply for impurity in oxygen or for evaporation of water. Whether the small correction for constant volume and for change in contents of the bomb need to be applied depends upon the degree of accuracy to which the operator expects to work.

2. Should it be required to burn charges giving much more or less heat than that used for standardization, with the oxygen supply and evaporation condition remaining unchanged, then it is most convenient to have the water value of the bomb determined with the smaller or larger charges also, and thus avoid the use of corrections.

3. When, however, the heat determinations must be made under varying temperature conditions, with different amounts of substance and various oxygen supplies, then all the corrections due to variation from the conditions at which the bomb was standardized must be applied.

The different water values for the bomb calorimeter used in this work corresponding to the above three methods of usage would be, including 2,000 grams of water:

Method 1, with 0.7142 gram benzoic acid charge, 2,421 water value.

Method 2, with 0.3614 gram benzoic acid charge, 2,425.4 water value.

Method 3, with 0.7102 gram benzoic acid charge, 2,415.7 water value.

In the third or last value, the corrections due to evaporation of water and specific heat of water have been applied.

### CORRECTIONS FOR IMPURITIES IN OXYGEN.

Having now the specific heat of combustion of benzoic acid, we can find from Tables 8 and 9 the correction for impurities in the oxygen expressed in degrees rise of temperature, or its equivalent in calories, for any given amount of heat generated in the bomb during a combustion. All substances do not affect the combustible gases alike, but for this purpose we may assume benzoic acid to be a representative substance, and each kind of material need not be tested separately. The average of six charges of benzoic acid was 0.7142 gram, which, multiplied by 6,320.8 equals 4,514.3 calories. This amount of heat caused a rise in temperature of 1.87257° C. with 20 atmospheres oxygen, and with 10 atmospheres oxygen a rise of 1.86652° C., a difference of 0.00605° C., which is equal to 14.62 calories. In like manner, the average charge, 0.3566 grams benzoic acid, Table 9, equals 2,254 calories and causes a total difference of 0.00357° C. rise, equivalent to 8.59 calories.

By interpolation we have, according to the various amounts of heat generated in 20 atmospheres oxygen pressure, the corrections for the oxygen shown in Table 12. They are applicable, of course, only to the particular sample of oxygen used in these determinations, and unless a uniform quality of the oxygen in this respect can be assured, it would be necessary to redetermine their factors for each cylinder of oxygen.

TABLE 12.—*Corrections for combustible gases in oxygen.*

| Heat generated in bomb. | Correction in terms of— | |
|---|---|---|
| | Rise of temperature. | Calories. |
| *Calories.* | *° C.* | |
| 4,500 | 0.00603 | 14.55 |
| 4,000 | 0.00550 | 13.22 |
| 3,500 | 0.00495 | 11.89 |
| 3,000 | 0.00440 | 10.57 |
| 2,500 | 0.00385 | 9.24 |
| 2,250 | 0.00357 | 8.58 |
| 2,000 | 0.00330 | 7.91 |

### BENZOIC ACID AS A STANDARD.

From his experience with various substances, and because of the value obtained for benzoic acid as described in this paper, the author in conclusion urges all persons using the bomb calorimeter for scientific work where results are to be published, for the sake of uniformity and comparability of results, to adopt benzoic acid as the one single standard against which to standardize the bomb, and to accept 6,322 calories per gram as its heat of combustion. This is the value accredited to Stohhmann, and this value ought to remain the standard until it has been definitely proved to be erroneous and a new value in some way officially recognized or accepted.

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BUREAU OF ANIMAL INDUSTRY.—BULLETIN 125, PART 1.

A. D. MELVIN, CHIEF OF BUREAU.

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# THE GID PARASITE AND ALLIED SPECIES OF THE CESTODE GENUS MULTICEPS.

## I. HISTORICAL REVIEW.

BY

MAURICE C. HALL,
*Junior Zoologist, Zoological Division.*

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1910.

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# LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
*Washington, D. C., June 16, 1910.*

Sir: I have the honor to transmit herewith, and to recommend for publication as a bulletin, the accompanying manuscript entitled "The Gid Parasite and Allied Species of the Cestode Genus *Multiceps*. Part 1. Historical review," by Maurice C. Hall, of the Zoological Division of this Bureau.

Mr. Hall has been making a most comprehensive study of gid, and his investigations will furnish an important contribution to our knowledge of this deadly disease of sheep, which has only in recent years been recognized as established in the United States, the first definite evidence of its presence as an enzootic having been published in 1905 in Bureau of Animal Industry Bulletin 66.

It is intended to publish later, as succeeding parts of the present bulletin, the results of Mr. Hall's investigations, now in progress, concerning the morphology and life histories of the parasites in question, as well as the symptomatology, treatment, prophylaxis, etc., of gid.

Respectfully,

A. D. Melvin,
*Chief of Bureau.*

Hon. James Wilson,
*Secretary of Agriculture.*

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# THE GID PARASITE AND ALLIED SPECIES OF THE CESTODE GENUS MULTICEPS.

## PART I. HISTORICAL REVIEW.

### INTRODUCTION.

Cœnurus is the name commonly applied to a larval cestode group of considerable importance to helminthologists from a historical and scientific standpoint, for it was with one of its species, commonly referred to as *Cœnurus cerebralis*, that Steenstrup's theory of the alternation of generations was first completely demonstrated for cestodes by Küchenmeister, who, in 1853, produced the adult cestode or tapeworm in the primary host by feeding the larval form to the dog, and produced the larval cestode or bladderworm in the secondary host by feeding the eggs of the adult tapeworm to the sheep. This work of Küchenmeister's and that of Von Siebold along the same line is taken by Braun (1894a),[a] in his classic work on cestodes, as marking the beginning of the fourth and latest period in helminthology, dating from 1851.

This same species, *C. cerebralis*, is of considerable economic interest to veterinarians and stock raisers, and especially to sheepmen, as being the cause of the disease commonly known among English-speaking people as gid.

In spite of the fact that the disease caused by this parasite, as well as something of its nature, was probably known in the fourth and fifth centuries B. C., and that the parasite itself was observed at least as early as 1634 A. D., its parasitic nature known since 1780, and its life history known for over half a century, there are still some mistaken popular ideas about it, and also some errors, disagreements, and uncertainties in the writings of scientists as to the specific identity of this and various other forms of cœnurus that have been described from different hosts, and also as to the correctness with which certain parasites are listed from certain hosts. The writer has endeavored to correct some of these errors in this paper, and it is proposed in a series of papers to give a comprehensive account of the cestodes having a cœnurus larva.

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[a] Bibliographic citations refer, wherever possible, to Stiles and Hassall's (1902–19—) Index-Catalogue of Medical and Veterinary Zoology, Authors, Bureau of Animal Industry Bulletin 39, United States Department of Agriculture. References not in Bulletin 39 are indicated by the use of Greek letters and will be covered in a supplemental bibliography, to be published later.

The first form to be considered is the brain bladderworm of sheep, usually known as *Cœnurus cerebralis*, but which, as will be shown, should be known by the name *Multiceps multiceps*, proposed here for the first time. In this article the word "cœnurus" will not usually be capitalized; it will be used merely as the name of a larval stage, like the words "cysticercus," "cercaria," "leptocephalus," etc. It is not entitled to be used as a generic or subgeneric name, owing to the priority of *Multiceps*, but as it is still much more commonly used in this way than *Multiceps*, and as reference must be constantly made to quotations where it is used in combination with some specific name, especially in the form *Cœnurus cerebralis*, it will often be clearer to use this form instead of the correct one.

## MULTICEPS MULTICEPS.

### HISTORICAL SKETCH.

Braun (1894a) makes his first period in helminthology cover the work of antiquity and the middle ages up to 1600, and in the literature of this period, relatively barren from a scientific standpoint, almost no references are to be found that can be construed as referring to gid. However, a disease like gid, involving, as it does, a delicate arrangement of alternating hosts, must have existed long before primitive man passed from the hunting to the pastoral stage. It is not the sort of disease to arise by rapid facultative adjustment or out-of-hand adaptation. The very fact that gid exists to-day is proof enough in a disease of this sort that it existed thousands of years ago. Undoubtedly, in the days when the ancestral dog pursued the wild sheep, the nice adaptation of a brain parasite that would interfere with muscular activity and blunt the sense perceptions, making flight and escape difficult, must have furnished a striking example of a life habit well calculated to perpetuate a parasite, but it could scarcely have been more satisfactory than the new arrangement introduced by man when he domesticated the sheep and put its former enemy, the dog, in charge of it to run over its pastures as a constant companion and to eat the discarded heads and diseased brains of giddy sheep—an enemy still.

A prolonged search of ancient literature would no doubt show some references which might readily be taken as descriptions of gid. The symptoms are so striking that pastoral peoples, like the Arabs, Jews, and Greeks, must have noted and described them; but finding such references involves a tedious search and more time than can profitably be spent on the work.

One such reference occurs in Kuhn's edition of Hippocrates (1825*a*), who is believed to have lived 460 to 375 B. C. The following is quoted from Adams's translation of Hippocrates (1886*a*), describing excess of fluids on the brain in epilepsy:

> This you may ascertain in particular, from beasts of the flock [i. e., sheep] which are seized with this disease, and more especially goats, for they are most frequently attacked with it. If you will cut open the head you will find the brain humid, full of sweat, and having a bad smell.

It is, of course, impossible to make a positive statement of fact on anything less than complete and accurate observations. Obviously there was no one in the time of Hippocrates who could be expected to make and record such observations in a case of gid, and existing editions of Hippocrates are open to the suspicion of having in them observations not properly referable to Hippocrates. Hence we can not say certainly that Hippocrates actually saw cases of gid, but on the strength of the reference given, agreeing as it does with the certainty that gid among sheep must have existed for ages, it is fair to state that Hippocrates probably saw cases of gid four or five centuries before the Christian era. The fact that the brain of sheep was found full of fluid points, among other things, to hydrocephaly, which may follow the invasion of the gid parasite, according to Müller (1877a), or to the gid parasite itself. Gid probably was not rare in those days when sheep were everywhere tended by dogs and the prophylaxis of the disease was undreamed of. The "bad smell" may have been due to delay in post-mortem examination, to hydrocephalus purulentus as a sequel of gid, or it may easily have been noted in the cœnurus vesicle, as my own observations show that the cœnurus fluid serves as an excellent medium for decomposition bacteria, the odor of the fluid in a graduate becoming intolerable in twenty-four hours at ordinary room temperature. Guetebruch (1766*a*), according to Küchenmeister (1880a), states in an article on gid that when perforation of the skull occurs, as it sometimes does in gid, the brain decomposes and becomes purulent, the brain and bone marrow turning to water and becoming putrid. The writer has never seen such a case, but it is evident that if the perforation of the skull were followed by perforation of the skin as well, it would afford entrance to bacteria, with possibly a result similar to the one given. Finally, the fact that these post-mortem findings are given for sheep suffering from "the sacred disease," a term covering epilepsy and other brain disorders, would indicate the possibility of gid, as the symptoms of nervous disturbances are very marked in this disease. Adams, the translator of Hippocrates from whom the foregoing quotation is taken, and himself a physician, refers to the lines quoted as follows:

> It is well known that this is also the case with sheep, and that they are subject to the disease called the sturdy [i. e., gid], which is indisputably a sort of epilepsy.

In the somewhat limited literature on helminthology for the period from 1600 to 1800, Braun's (1894a) second period, the gid parasite figures to a proportionally large and increasing extent. The citations from this period are given rather fully, as they are in works which are not readily available to many.

In the first part of the nineteenth century, Braun's (1894a) third period, there are numerous references to gid, and since 1850 and the work of Küchenmeister, which was done soon after, not a year has passed in which few to many notes on the brain bladderworm, its adult tapeworm, or its effects, have not appeared. This increase in the amount of literature is perhaps concomitant with an increase in number and distribution of sheep and cases of gid, as well as with increasing knowledge of the parasite. In general the large amount of literature is due to the attractive combination of scientific and economic interest which has induced many persons to publish notes on the disease and its parasite from one or both standpoints.

The early notes on cœnurus deal only with *Cœnurus cerebralis* (= *Multiceps multiceps*) and especially with the disease caused by it. It was nearly two hundred years after Scultetus (1672a) had seen the first unmistakable case of gid that I have found recorded, before the first cœnurus which we may regard as other than *C. cerebralis* was noted by De Blainville (1828a). Scultetus saw his case in 1634.

The first available note published during Braun's (1894a) second period of helminthology dealing with *C. cerebralis* is that of Rolfinck (1656a) who, in a work on medical anatomy, writes of vesicles full of water and humor in the third ventricle of sheep as the cause of a vertigo. This may be safely accepted as a reference to *C. cerebralis*. The description is in general terms just the one a casual observer would give of this parasite, as witness the statement of a correspondent to the veterinary editor of a periodical (Vet. Ed. Amer. Shepherd's Bulletin 1903$\gamma$) to the effect that he found in a sheep's head "a bag of water which burst and ran out when I pressed upon it."

The next available article on the subject of gid published during this period is that of Wepfer (1658a). The part relating to *C. cerebralis* gives at this early date notes on the characteristic symptoms of the disease, its pathology, and the morphology of the water bladder. The disease is further recorded as a frequent cause of death in cattle, and the peasants are credited with a form of operation involving percussion and surprisingly good for that date.

Heusinger (1853$\alpha$) quotes from a work of Bartholinus (1667$\alpha$), not available to me, a statement of a species of frenzy and vertigo which in 1661 attacked horses, cattle, and sheep, and notes that worms were found in the heads of the animals attacked. These cases may have included, and very likely did include, cases of gid.

The next available article dealing with *C. cerebralis* is that of Scultetus (1672a), who in a Latin treatise on surgery gives the description of a case seen at the earliest date at which we have found a case recorded. The following is quoted from an English translation of the same work (Scultetus, 1674a):

> Observation X. Of a Vertigo in a Sheep, proceeding from an Abscess in the Brain. In the Year 1634, December the 24th. Being in the shop of Nicolas Kite[a] he made mention of his sheep, among which one was troubled with a Vertigo, or Giddiness, the Germans call it *Wirbling:* this Disease one who dealt in sheep affirmed to be incident to the fairest of the Flock; that hereby their whole Brain would be turned into Water and then they would fall down dead on a sudden. The Chyrurgion therefore commanded that one of those sheep which was weakened with this Giddiness, and turning around, should be killed, and sent me the head.

Scultetus found nothing in the ventricle.

> Afterward I lifted up the organs of smelling * * * and on the left-side, between the Brain and the Pia mater, I found an abscess, like the Bladder of a Fish, full of very clear water * * * I wondered that * * * the sheep should not labour under an Apoplexy, or a Palsy, rather than a Vertigo.

In 1645 Scultetus lost a sheep by the same disease, and in the work just noted writes:

> I dissected the Head * * * and presently on the left-side as it were of the backward part of the Head, under the Dura Mater, I found a Bag of the thickness of a Fisches Blader, filled with Water, and little Worms, such as are bred in Cheese; for it began to putrefie at the bottom. This Coated Tumour being bigger than a Hens Egg, had so insinuated itself into the substance of the Brain, that it did somewhat press upon the third Ventricle. This Sheep, as the Shepheard reports, turned herself round about towards the night[b] all that day she dyed.

That gid was not uncommon in the seventeenth century is clear from the fact that Rolfinck (1656a), writing of vertigo, refers to it as *occasionally* (nonnumquam) caused by sacs of water on the brain in sheep. Wepfer (1658a) notes it as a serious and common disease of cattle in Switzerland. In the account of Scultetus (1674a) it appears that a sheep dealer recognizes the disease as one common enough in Germany at that time to have a colloquial name, "Wirbling."

The next reference to gid is by Wepfer (1681a) and is identical with the one already given, being in a later edition of the original work of 1658.

Küchenmeister (1880a) refers to an article by Brunner (1694*a*), not available to me, and quotes from it a statement to the effect that Brunner had dissected the head of a giddy calf, "vituli vertiginosi," and in the cerebral substance had found three hydatids the size of pigeon eggs and full of limpid fluid. Küchenmeister takes this to refer to *Cœnurus cerebralis*, which it obviously does.

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[a] The original Latin text reads "in tonstrino Nicolai Reutte." The translator has translated not only the text but also the proper names, rendering the German name Reutte by its English equivalent, Kite.

[b] This last statement should read "towards the right," the Latin word here being "dextram."

The next reference is in Wepfer (1724a). The first two parts of this article consist of the two parts making up the edition of 1658. With these is incorporated a third part. The same references to gid occur in the parts already published and referred to above. In the new part is a new reference to hydatids in the brain of cattle as being commonly believed to be the cause of the vertigo accompanying them. He has seen the peasants perforate the skull and extract these in operations and has also seen the hydatids demonstrated post-mortem.

Hoffberg (1759a), in a dissertation on *Cervus tarandus*, first presented in 1754, writes under the heading of diseases of this animal, of a vertigo or "Ringsjuka" causing the reindeer to turn in circles. Braun (1894a) takes this as a reference to *Cœnurus cerebralis*, which is a perfectly reasonable assumption. The presence of the parasite in the reindeer, however, is unsupported by post-mortem evidence in this reference, and, so far as I am aware, such evidence is lacking in any subsequent writings. The occurrence of the gid parasite in the reindeer must therefore be considered doubtful. It seems the more doubtful in that Brehm (1877*a*) states that reindeer are attacked by the larva of a gadfly, specified by Moniez (1880a) as *Cephenomya trompe*, which penetrates from the nasal cavity to the brain, causing a fatal "Drehkrankheit" or gid, and it may have been this disease, apparently a common one, which Hoffberg saw.

Küchenmeister (1880a) quotes from a treatise on diseases of sheep by Guetebruck (1766*a*), already noted as not available. In this treatise it is stated that the disease attacks lambs and yearlings, but not old sheep; that some are born with it; that a water bladder forms on the brain and may penetrate the skull; that when the disease has not gone too far the flesh may be used and the head and feet thrown away [very bad advice], but if the disease has gone too far the entire carcass should be done away with. As a method of treatment he gives venesection on the temple and nose.

Stier (1776a) has an article on gid, of which only the review was seen by me, the original (Stier, 1775a) not being available. The article takes up a long list of supposed causes of gid and rejects them, the water bladder in the head being held guilty of causing the trouble. Stier also draws a careful distinction between actual gid due to *C. cerebralis* and simulated gid due to the presence of *Œstrus* larvæ in the nostrils, the latter presenting the symptoms most commonly mistaken for gid.

According to footnotes in Bloch (1780a), Hastfer (1776*a*) and Ranstler (1776*a*) have published references to gid, but these are not available. Bloch states that they attributed gid to the bladder on the brain, and that Ranstler was the first to notice the small bodies on the bladder and surmised that worms arose from them.

According to Braun (1894a) and others, the cestode nature of the water bladder found in the brain of giddy sheep was first pointed out by Leske (1780a) and by Goeze (1780a), independently. These references are not available to me. Braun notes that Goeze recognized the cestode heads and considered them as the embryos of the bladderworms which are found in the omentum and liver of sheep and swine. He also notes that Leske found *Tænia multiceps* (= *Cœnurus cerebralis*), recognizing the characteristic hooks and suckers. Küchenmeister (1880a) quotes part of Leske's article showing that Leske made a very careful study of the morphology and pathology of the parasite. He noted the heads invaginate and evaginate through the bladder wall. From the presence of so many of these heads, he observes that we may consider the animal as many tapeworms attached to a common bladder, or as one tapeworm with many heads. Hence it would be appropriate to call it the many-headed tapeworm, so he names it *Tænia multiceps.*

This last is important, as it establishes the fact that the correct specific name of the gid parasite is *multiceps.* The preceding note from Braun (1894a) confirms the correctness of Küchenmeister's (1880a) quotation, and in addition Mr. Sherborn has very kindly verified the reference in the library of the British Museum. It appears from evidence to be considered later that Leske's work antedates that of Goeze in the same year. Were it otherwise, Goeze's article need not be considered, as, according to Braun's synopsis, he regarded the heads of the parasite as the embryos of the bladderworms found in the omentum of sheep and swine, and hence presumably proposed no new name for the brain parasite, as there would be no reason for it under the circumstances or a proper application for the name had he done so.

In a discussion of the synonymy of this parasite, Stiles and Stevenson (1905a) accept as the specific name the one proposed by Bloch (1780a). Bloch makes the genus *Vermis vesicularis* for the bladderworms, and divides these into three species, of which *Vermis vesicularis socialis* is the brain bladderworm of sheep. But though this article of Bloch's bears the same date as those of Leske and Goeze, viz, 1780, Leske's article is nevertheless older, and the name proposed by him is therefore entitled to priority. This is evident from Bloch's own article, which shows that Bloch had read Leske's article of the same year. Bloch states that Ranstler first noticed the small bodies on the bladder walls and surmised that worms arose from them, but that Leske and Goeze observed that these bodies were actually bladderworms. He states that Leske has described them very completely and figured one accurately. Bloch very significantly adds that Leske numbered the parasites among the tapeworms, "Bandwürmer," where, according to Bloch, they can not properly be reckoned, for reasons already given by him.

It is evident from the last statement that Bloch had not overlooked Leske's *Tænia multiceps* and that he believed he was correcting an error by proposing the name *Vermis vesicularis socialis*. However, subsequent work on cestode life history has shown the invalidity of all classifications which place vesicular worms in a group apart from the strobila forms and has justified Leske's judgment in uniting them.

Unfortunately for Leske's name, Rudolphi (1810a) did not list it as a synonym of *Cœnurus cerebralis,* although he listed Leske's article in his bibliography. For this reason Leske's name has been very generally overlooked, as research in nomenclature has commonly gone back through Rudolphi to the names quoted by him. Stiles and Stevenson (1905a) do not give Leske's name, *Tænia multiceps,* in their table of synonymy, and in selecting the oldest name available to them have overlooked the rather obscure references to Leske's unavailable article. On calling Doctor Stiles's attention to the omission he pointed out to me that Sherborn (1902a) refers to Leske (1780a) with the comment "No n. spp." I wrote Mr. Sherborn, asking him to verify this reference, which he very kindly did. In a personal communication he quotes substantially the part quoted by Küchenmeister (1880a), and states that he overlooked the name in his former reading. Mr. Sherborn was also good enough to supply copies of Leske's illustrations. These show very close observation.

Following the independent discoveries by Goeze and Leske of the cestode nature of the water bladder from the brain of giddy sheep, there arose some controversy as to which of them was entitled to priority. According to Braun (1894a), Boerner (1780a) published an article discussing this point and holding Goeze as the discoverer. Subsequently, Goeze (1782a) repudiated Boerner's article, deploring the misunderstanding between himself and Leske. He states that he has explained the situation in a previous publication, the date of which is not given and which is unavailable to me. Leske's priority is conceded by Rudolphi (1808a) and by Davaine (1860a). The matter of priority here is apparently not concerned in the nomenclature, and what honor lies in priority of discovery belongs to Leske, so far as the available evidence shows.

Goeze (1782a) divides his genus "*Tænia,* Bandwurm," into two main classes as he calls them—*Tænia visceralis*, the visceral tapeworms, and *Tænia intestinalis*, the intestinal tapeworms. Under the former he lists, among other species, "*Tænia vesicularis cerebrina*" from the brain of giddy sheep, *Multiceps*, the many-headed, with many heads and bodies in a common bladder. And later on he states that from the numerous heads one may call the parasite "Vielkopf (*Multiceps*)."

From the above, Stiles and Stevenson (1905a) have taken the generic name *Multiceps*. The generic name used by Bloch (1780a) is evidently unavailable, being composed of two words and therefore contrary to Article 8 of the International Code of Zoological Nomenclature, as given by Stiles (1905y): "A generic name must consist of a single word, simple or compound."

Rudolphi (1809a) rejected Bloch's *Vermis vesicularis* as incongruous and unsystematic. Sherborn (1902a) is in error in listing *Vermis* Bloch 1782 as a generic name. The combination *Vermis vesicularis* is always used, whether with or without various specific names attached.

As heretofore shown (p. 11), the earliest specific name of the parasite is that of Leske (1780a) as given in the name *Tænia multiceps*. If the parasite in question is to be removed from the genus *Tænia*, then the new combination must use the earliest available generic or subgeneric name, and since Goeze's (1782a) use of the scientific name *Multiceps* is evidently generic or subgeneric in intent, being clearly used to distinguish the many-headed gid parasite from the single-headed cysticercus forms, it is necessary to use it in the new name.

The tendency for some time, and certainly a desirable tendency, has been to break up the large and heterogeneous group of animals formerly listed in the genus *Tænia*, and to restrict the use of this name. The present situation has already been stated by Stiles (1905y) as follows:

> Most authors recognize that *Tænia* is to be divided into the subgenera *Tænia*, *Multiceps* (i. e. *Cœnurus*), and *Echinococcus*. Some authors, however, incline to recognize these subgenera as of full generic rank.

It seems advisable to restrict the generic name *Tænia* to those forms which have a cysticercus stage in the life history. These alone make up a large group with a fairly close similarity in the adult and larval stages. To retain in this already large genus forms having a cœnurus or echinococcus larva seems unnecessary and undesirable. Long ago Leuckart (1886d) wrote:

> The *Cœnurus* * * * is related to the *Cysticercus* as a compound to a simple animal—a sufficient reason for systematic zoologists to separate them.

Generic rank is accorded to particular groups of species which in the course of evolution have attained distinctive characteristics, and I see no reason for withholding such rank from forms in which these distinctive characteristics occur in the larva instead of the adult. This point is of especial importance in a case of this sort where the animal is found in the larval stage in the great majority of cases, the adult being seldom seen or recognized. This view is in accord with that of Stiles and Stevenson (1905a), from whom the following is quoted:

> Opinions may differ as to whether this group [*Multiceps*] should be given generic or subgeneric rank. Personally we see no serious argument against recognizing a distinct genus on basis of the "larval" stage.

Adopting, then, the genus *Multiceps* Goeze, 1782a, and the species *multiceps* Leske, 1780a, as the oldest available names, the correct technical name of the gid parasite is *Multiceps multiceps* (Leske, 1780a), Hall, 1910$\beta$.

From 1782 to 1800, the latter date marking the beginning of Braun's (1894a) third period in helminthology, numerous observations were made on gid, most of them merely confirming the previous work of Leske, Goeze, and Bloch, or adding minor points of more or less importance and interest. By 1800 the gid disease had been observed certainly for over a century and a half and very likely for twenty-two centuries, its parasite had been named, described, and figured, and had a fairly large number of synonyms in addition to its correct name, the symptoms and pathology of the disease had been given, together with the symptoms of diseases simulating gid, and methods of operation had been used which only lacked aseptic precautions to make them equivalent to good modern methods, and which were as good, perhaps, as most methods now in actual use.

There remained, then, the work of finding out the life history and basing on that a rational prophylaxis. As a matter of fact the discovery of this life history by Küchenmeister and Von Siebold marks the beginning of the fourth and last period in helminthology. The contributions of the third period to the subject of gid are largely wrong and unnecessary theories of causation as well as unsatisfactory methods of treatment. In addition, the large amount of literature in this period lists the parasite from several new hosts, often erroneously, and adds considerably to the synonyms by which it is known. During this period new records of the disease show a widening geographical distribution, and unsatisfactory and unsubstantiated statements of its presence in the United States begin to appear as early as 1809. The essential contributions in the literature of this period have been covered in tables and discussions to be given later, and the important events marking the modern period of helminthology may next be considered.

Von Siebold (1844a) proposed as an explanation of the true nature of bladderworms that they were cestode embryos which in attaining a new host had gone astray, ending as encysted, incompletely developed forms. Thus *Cysticercus fasciolaris* of the mouse was held to be such an incomplete sexless modification of *Tænia crassicollis* of the cat. He ventured to predict that in time the various tapeworms would be identified in their relation to certain cysticercus, cœnurus, and echinococcus forms.

Dujardin (1845a) advanced a similar theory, and this view or modifications of it became popular in scientific circles during the five or six years following Von Siebold's publication. It required the experimental work of Von Siebold and Küchenmeister in 1851 and 1852 to complete this half truth. In the meantime the advocates of spontaneous generation lost ground to those who urged that the bladderworms were altered, degenerate cestodes or were incompletely developed embryonal forms.

A prominent champion of the last theory, Küchenmeister (1851e), finally published a note stating that he had produced *Tænia crassicipes* [= *T. crassiceps*] of the fox by feeding *Cysticercus pisiformis*. A little later (Küchenmeister, 1851d) he corrected this statement, changing his identification of the adult worm to *T. serrata*. This marks the beginning of the modern use of the now general experimental feeding methods of determining life histories.

It remained for Von Siebold (1852a), the supporter of the theory of hydropic degeneration of bladderworms, to furnish additional proof that his theory was wrong, for this same year he produced the adult cestode from the gid bladderworm.

The following year Küchenmeister (1853e) succeeded in experimentally demonstrating, for the first time, the entire life history of a cestode. He fed *Cœnurus cerebralis* to a dog and produced a tapeworm which he called *Tænia cœnurus*. He then fed the gravid proglottids of this tapeworm to a sheep, and produced in it the early stages of the cœnurus in the brain.

From this experiment Küchenmeister concludes that sheep are infected in pasture by dogs dropping proglottids. Other animals, he thinks, may also harbor the tapeworm, and he claims this would certainly be true of wolves in Hungary and Poland. This statement is evidently mere assertion, as it is not verified by the record of such a finding either at the time or subsequently. At this date no description of *T. cœnurus* had been published and its anatomy had not been studied. Indeed, the following year Von Siebold (1854b) states that he finds the adult of *Cœnurus cerebralis* to be *Tænia serrata*. While the occurrence of *T. cœnurus* in the wolf is a probability, it is nothing more, so far as all available records show.

On the evidence at hand Küchenmeister formulated a set of rules for the prophylaxis of gid which is practically complete. It is as follows:

1. Feed dry food the year round and do not pasture.
2. Once or twice a year, purge the sheep and dogs in some inclosed place to get rid of tapeworms, and burn the feces.

3. Do not, as is usually done, throw the heads of giddy sheep to the dogs, or, as Küchenmeister after investigation finds to be done, throw the brain to the dogs before cooking the heads. Where there are wolves one must also bury or burn the intestines of those that are killed, and not throw them away to infect the fields.

Such a program is not altogether practicable or necessary, but it only needs trifling amendment to bring it down to date. Had it been adhered to only as regards keeping dogs free from tapeworms and heads of giddy sheep away from carnivora for the last half century, gid would probably have been a rare disease by this, for it is really one of the most readily preventable of diseases.

The next year Küchenmeister's work was confirmed by Von Beneden (1854$\alpha$ and 1854$\beta$), Eschricht (1854$\alpha$), Gurlt—according to Küchenmeister (1854$\alpha$)—Haubner (1854c and 1854d), Leuckart (1854c), and Röll (1854$\alpha$), all of whom produced gid in sheep by feeding proglottids of *Tænia cœnurus* sent them by Küchenmeister.

As a result of these experiments and others performed soon after, the important phases of the life history of the gid tapeworm were determined. It was found that the disease began with an invasion period during which the embryos were migrating through the body. Then followed an interval of apparent recovery, during which the growth of the bladdery vesicle was going on, to the point where the heads became developed and exsertile. Here the third and final stage of gid occurred, the characteristic symptoms, corresponding to particular locations of the parasite, becoming more aggravated with the increase in growth and number of heads until death occurred.

Subsequent work has added to our knowledge of the morphology of the gid parasite, of the symptoms, pathology, and simulation of the disease, and of the need of avoiding bacterial infection in operation. It has added numerous synonyms to the nomenclature, and recorded, correctly or incorrectly, new hosts and new areas of infection, among the latter the United States. No essential points have been added to our knowledge of the life history of the parasite or the prophylaxis of the disease.

### GID IN THE UNITED STATES.

The history of gid in the United States is, to a remarkable extent, a matter of conjecture. So far as I have been able to discover, the first claim of its occurrence here was made a century ago by Livingston (1809$\alpha$). His claim is based on very unsatisfactory evidence. The following is a rather full quotation of the case:

> The staggers or dizziness, which is also known by various other names, has occurred in three instances in my flock, and always attacked lambs under one year. * * * They were taken very suddenly * * * by a species of convulsion, in which the neck was twisted to one side; they lost the use of their legs; when raised they would

> attempt to follow the flock, but turned round and fell; in a few days they were incapable even of standing, of moving their heads or any of their limbs. As they were very valuable sheep, I paid particular attention to them; grass and grain were given them, which they would readily eat, though they could not move any part but their jaws. In this state they lay a week without motion, except of their eyes and mouth. * * * In about ten days they could stand without support, but fell when they attempted to walk. * * * At intervals they would get better * * * but they were always found laying in some part of the field as if they were dead. * * * In the course of about six weeks they so far recovered as to be able to join the flock; one of them * * * received a blow * * * that killed him; the other two recovered, but very slowly; and even at the end of eight months they bore evident marks of their complaint. This disorder is found, upon dissection, to be owing to a bag containing water within the skull. * * * It may * * * be justly considered as incurable by the doctor, but not, as I have shown, by the nurse. * * * But a sheep must be extremely valuable to pay for three months' constant attention.

It seems unlikely that the above cases were gid. Their occurrence in lambs fits in with the theory of gid, and the general symptoms, though not typical, might have been gid. On the other hand, the alternation between periods of normal activity and entire collapse does not look like gid, and the gradual betterment over a period of eight months runs counter to the clinical history of the disease. Moreover, leaving out the case of the lamb that was killed while recovering, the per cent of recoveries was 100. Some writers have claimed a spontaneous recovery in 2 per cent of all cases, but the writer knows of no evidence showing that any cases ever recover when the formation of the bladder is once under way, and a degeneration of the parasite in its earlier stages, indicated by the brain concretions according to Spinola (1858b), would not give a long period of slow recovery. Moreover, the three scattering cases given would indicate a sporadic infection, not to be expected in the case of gid. Doctor Mohler of this Bureau suggests a meningitis as the particular disease simulating gid in this instance, a theory which seems to fit the case very well. The lack of post-mortem evidence is unfortunate, as even typical cases of gid may be simulated by other things.

Cole (1847$\alpha$), in a book published in Boston, discussing "Sturdy, or Water in the Head," states:

> A writer on this subject says that he knew a shepherd in Europe that saved nearly all on which he operated in this manner [by trocar], while he himself lost nearly all on which he operated.

This sentence suggests that the writer referred to had operated outside of Europe and most likely in the United States, but this is, of course, mere speculation.

Later, a competent scientist, Leidy (1856a and 1856b) records *Cœnurus cerebralis* in a list of parasites "observed by the author," but does not state whether it was collected in the United States.

McClure (1870$\alpha$), writing from the United States, says that he has known as many as five cœnuri to occur in the brain of sheep. He does not specify that this observation was made in the United States, however, or that the disease occurs here.

Verrill (1870d), writing of gid, says: "In this country [United States] the disease is far more common than most persons suppose." Unfortunately, he cites no literature and no cases in support of this statement, and a request for further information has not been answered.

Tellor (1879a) says: "Hydatid in the brain, or turnsick, although reported from New York and other States, is a curiosity rather than a scourge." He does not claim to have seen the disease.

Crutchfield (1880*a*), of Hamilton County, Tenn., says:

> I have lost a few sheep by "staggers," "turnsick," etc., properly Hydatid on the brain, by allowing the sheep to range upon low, wet, spongy lands. By removing them at once the disease ceased.

The evidence here is not sufficient to enable one to pass judgment on the case. There is no statement of symptoms or autopsy findings, and the cessation of the disease on removing the sheep from low, wet ground might or might not have followed in the case of gid. Hence this case must remain uncertain.

Killebrew (1880*a*), writing from the same State, Tennessee, in the same year does not claim to have seen the disease, but Stewart (1880a), writing from New York, says of *Cœnurus cerebralis:* "The presence of this parasite has been discovered * * * in numerous sheep in this country."

Stewart's statement is not convincing, but in connection with other things it shows a belief on the part of men interested in the sheep business that gid existed in this country. Later events indicate that their belief and their statements to that effect are quite as likely to have been based on fact as to have been unfounded.

Wernicke (1886a) records *C. cerebralis* from sheep in Buenos Aires. He believes it imported from Europe and states that it is a source of worry to breeders. It seems altogether likely that if gid had been imported to South America from Europe by 1886, it had probably been imported to the United States from the same source even earlier. In this connection, Powers (1887*a*) writes from New York the following year concerning gid:

> I have never seen a case of this, knowing it to be such, nor have I seen an American shepherd who has met with it. It was probably imported from England, and it seems to prevail chiefly in the Eastern States. * * * I made many autopsies of sheep * * * for the bladder or cyst of this parasite, but I never found one. When the case is long drawn out, the bladder or tumour on the brain by constant pressure on the skull, absorbs it to such a degree that a finger pressed on the spot discovers a soft spot in the plate of the bone, or the latter even bulges out in a protuberance. * * * Twice I have seen this phenomenon in my own flocks and in rude fashion lanced them, thereby saving the sheep.

There is an evident contradiction between the statement that the writer has never seen gid and that he has operated on his sheep for it.

How easy it would be to import a case of gid may be surmised from Rabe's (1889a) case in a gazelle imported from South Africa fourteen days before death. There is also the possibility of importing the adult worm in some of the numerous dogs which have been imported to this country. Professor Law, in a personal communication, writes under date of July 2, 1909:

> Owing to its rapid development in the lamb it is less likely to be imported in the condition of larva, but among the many imported dogs the *Tænia* must have been often imported.

All things considered, the likelihood of importing the disease via the dog is perhaps as great as that of importing it in the sheep, but I would not consider the latter less likely. Rabe's case and others to be considered later show this. Moreover, a possible four to six months is not a very rapid development of disease in these days of rapid transit. An outbreak of gid attributed by Doctor Law and by Taylor and Boynton (1910a) to imported dogs is discussed later in this paper. The writer has collected evidence in Montana indicating that the gid parasite has been imported in dogs in some instances and the disease spread by the sale or gift of these dogs and their offspring.

Nearly twenty years ago, Curtice (1890c) writes of larval cestodes in sheep: "*Tænia marginata* is more common in the United States, and *T. cœnurus* next." He hazards the guess that in the West wolves, coyotes, and foxes may harbor the parasite. In a personal communication Doctor Curtice writes of the above under date of July 26, 1909: "I have never seen *T. cœnurus*. I must have made statement on information by reading."

In another article Curtice (1892g) has the following:

> The tapeworms identified as *T. cœnurus* were found but once in Colorado. The species may have been one arising from rabbit cysticerci and wrongly identified. The specimens were taken from a sheep dog. They are now in the bureau collection.

I have examined these specimens (Nos. 2839 and 2840), and while they are not in good condition it is still possible to determine the essential things. They are not *T. cœnurus*, so far as the material furnishes data on the subject. To mention two evident differences, the eggs are decidedly oval, and the handle of the large hook is of an entirely different shape.

About the year 1895 the subject of gid in the United States begins to receive notice in sheepmen's periodicals. Thus we find gid diagnosed by the veterinary editor of one paper (Vet. Ed. Amer. Sheep Breeder, 1895*a*) in a case where correspondents from an unspecified locality give a history of staggering to the right in an imported

Shropshire ewe. The animal became unable to rise and was killed. On post-mortem examination a third of a teacupful of water ran out of the head. We are obliged to concur in the diagnosis given and consider that the disease was very likely imported with the sheep.

Later in the same year the same diagnosis is given by this editor (Vet. Ed. Amer. Sheep Breeder, 1895β) in a second case from an unspecified locality, with the characteristic symptoms of giddiness or turning, followed by death. Another case is diagnosed as gid on the same symptoms two years later (Vet. Ed. Amer. Sheep Breeder, 1897β).

Sommer (1896c) did not find *T. cœnurus* in an examination of fifty dogs at Washington, D. C.

The adult tapeworm, *T. cœnurus,* was reported from Nebraska by Ward (1896b), but Stiles (1898a) on an examination of the head of the specimen pronounced it *T. serialis.* Doctor Stiles tells me that he based this identification on the bifid guard of the small hook, an inadequate diagnostic character, as the corresponding guard of *T. cœnurus* is also bifid. (See Reinitz, 1885a, and Ransom, 1905d.) On the other hand, the larva and adult of *T. serialis* are known to occur in Nebraska, which makes it likely that Stiles was correct. Ward (1897b) agrees with Stiles that it was *T. serialis.*

Knowles (1897α) writes as follows:

> As numbers of inquiries come to this office relative to gid, or staggers, or so-called turnsick in sheep, I * * * append a well-written description, etc., of this disease by Doctor Curtis. [This should be Curtice.]

Doctor Knowles tells the writer that he saw his first cases of gid in Montana during the year that the above was written, 1897.

Stiles (1898a), writing from this laboratory, says of *Cœnurus cerebralis:*

> Fortunately it does not seem to be prevalent in this country. * * * It has been impossible for the writer to find any possible evidence of the existence of the gid bladderworm in this country, yet in view of the importations from Europe of sheep and dogs it is difficult to believe that we are entirely free from this parasite.

In a footnote he says:

> One extremely doubtful case has been reported to us from Minnesota of its occurrence under the skin of a horse. This latter case has not been examined by the bureau, but I would suggest that *Tænia serialis* is common in America, and considering the tissue in which this parasite was found, it is not at all improbable that the Minnesota case was one of *Cœnurus serialis* (*Tænia serialis*) rather than *C. cerebralis.*

Railliet's (1893a) earlier note of this case is based on correspondence.

As this case stands we may choose between considering it as the first and only case of *C. serialis* in the horse and in its normal location, or regarding it as one of several cases of *C. cerebralis* in the horse, occurring in a location in which it has been reported twice from the sheep. The case is too doubtful to pass judgment on, and the report may have been an error in the first place.

Wallace (1900a) diagnoses a case for a correspondent from Iowa as gid in sheep. The symptoms are suspicious, but not clearly gid.

Shaw (1901a), writing of the sheep industry of Minnesota, says that gid "has not been markedly prevalent in Minnesota." In a personal communication dated July 27, 1909, Professor Shaw writes:

> I have seen cases which I supposed to be gid in sheep, but I have never seen the parasite itself * * *. Dr. H. M. Reynolds, veterinarian of our [Minnesota] station * * * tells me that his experience is similar to mine. He has not yet seen the parasite.

The veterinary editor formerly referred to (Vet. Ed. Amer. Sheep Breeder, 1901γ and 1901δ) diagnoses a case as gid in reply to two correspondents from Montana who describe the symptoms and post-mortem findings of their sheep. The diagnosis is unmistakably correct. He states (1901δ) that gid is "fortunately not very common except in the native sheep of the plains." Strictly speaking, the only native sheep in America are the Bighorn sheep, *Ovis montana*, of the mountains, never reported as subjects of gid. The reference is perhaps to native-bred sheep. The diseased sheep in this case came from Colorado, and the editor states:

> It [*C. cerebralis*] is especially common in Colorado, where 70 per cent of sheep examined by Doctor Curtice were infested by it. It is unquestionably quite as common in all the western country from Mexico as far north as the animals mentioned [foxes, wolves, and coyotes] exist.

It has already been noted that Doctor Curtice says that he has never seen *T. cœnurus*.

Finally the editor states that he has recently operated on seven sheep for gid. This is the first record of what appears to be a clear case of the finding of the parasite in the United States. On attempting to secure further information about these cases it was learned that the veterinary editor in question was deceased.

In another sheep-breeders' periodical (Vet. Ed. Amer. Shepherd's Bulletin, 1902α) a case from Illinois is diagnosed as probably gid. The symptoms are quite characteristic—slobbering, refusal to eat, turning always to left, head held down to left, death the fourth day. The case was probably gid. The editor states that he has seen gid in England, but not in the United States, though he claims that there is reason to suppose that it occurs in imported sheep.

Law (1903a) says of the adult tapeworm from *Cœnurus cerebralis:* "The writer raised forty-two, averaging 1 foot, in six weeks in a sucking puppy." Doctor Law writes in a letter of July 2, 1909, already noted, that this was done in Edinburgh, Scotland, in 1864 or 1865, and that he has not seen gid in America.

Cases from Nevada, showing the symptoms and post-mortem evidence of gid, are so diagnosed by the veterinary editor of the American Sheep Breeder (1903α). Some cases from Kansas and Iowa, with symptoms of gid, but no post-mortem findings, are also diagnosed as gid. (Vet. Ed. Amer. Sheep Breeder, 1903β and 1903γ.)

The same year, the veterinary editor of the American Shepherd's Bulletin (1903α) states that the disease is prevalent in Utah and common in other sections. He diagnoses gid in two imported rams in Michigan (Vet. Ed. Amer. Shepherd's Bulletin, 1903β)—the diagnosis seems correct from the characteristic symptom complex—and gives the report of an operation (Vet. Ed. Amer. Shepherd's Bulletin, 1903γ) from an unspecified locality where some one found a "bag of water" on the sheep's brain.

The next year, Stiles (1904s) wrote of *Cœnurus cerebralis:* "I have never seen any specimen of this parasite collected in the United States."

The same year, an outbreak of gid occurred in Montana, a discussion of this outbreak being given the following year by Ransom (1905d). In that article Ransom states:

> Until very recently, so far as it has been possible to determine, gid has been entirely unknown in this country. * * * It seems hardly probable, in view of our present knowledge, that the disease has been altogether absent * * * The disease is now present in the United States, cases having developed recently which, as the attendant circumstances show, must have resulted from infection in this country.

The sheep in question died at Bozeman, Mont. A comparison of the cœnuri obtained showed a complete agreement with the description of the European *Cœnurus cerebralis*. Ransom's article pointed out the danger from this disease and the means of combating it.

In addition to Ransom's cases of gid from Montana, the veterinary editor of the American Sheep Breeder (1905α-ζ) answers a number of letters from which it appears that gid was present the same year in Missouri, Kansas, Ohio, Colorado, Indian Territory, and other localities not specified. The symptoms were quite characteristic in the Missouri cases and were confirmed by post-mortem in the cases from Ohio and the Indian Territory. These cases are, in my opinion, undoubtedly gid, and the Kansas and Colorado cases are possibly gid.

Clarke (1907α) states that he has met many cases of gid in sheep at the slaughterhouses, but in a personal communication of August 2, 1909, he writes that this was in England.

Wing (1907α), after many years experience with sheep, states that he is not sure that he has ever seen an instance of gid.

Kaupp (1908α and 1910α) has overlooked the work of Ransom (1905d), as well as some other articles we have cited, and states that gid is not reported in the United States.

Luckey (1908$\alpha$), writing from Missouri, states: "Although not very common in this State, what is known as sturdy or gid in sheep causes some loss."

Regarding this, Doctor Luckey writes, under date of July 21, 1909, that he has not kept an accurate record of outbreaks, but remembers a report from Willow Springs, Howell County, describing perfectly the symptoms of gid in goats. This is the only case known to me where gid has been reported from the goat in the United States, and it is included in a subsequent list as a probable case.

The veterinary editor of the American Sheep Breeder (1908$\beta$) diagnoses as gid a very doubtful case in an Iowa sheep, and elsewhere (Vet. Ed. Amer. Sheep Breeder, 1908$\alpha$) states that the disease is very prevalent at the time in some parts of the United States.

The writer (Hall, 1909$\alpha$ and 1910$\alpha$) has twice reported gid from the United States, once with a record of cases.

The official files of this Bureau furnish additional data, mostly obtained through inquiries by Dr. B. H. Ransom, chief of the Zoological Division of the Bureau. Dr. S. W. McClure, Bureau veterinary inspector, Pendleton, Oreg., in addition to furnishing this division with specimens of giddy sheep, further informs us under date of September 3, 1906, that a highly reliable sheep man of Chouteau, Mont., claims to have had gid among his yearlings "for many years," having 40 to 60 affected every year out of 2,000. Many other Montana sheepmen, according to Doctor McClure in a letter of October 15, 1906, claim to have the disease in their flocks. One claims to have 15 to 20 cases some years, another had over 200 cases among 10,000 lambs in 1905, another had 30 cases among 4,000 lambs in 1898, another had 15 cases among 1,500 bucks in 1906, and others had a few cases each year. Doctor McClure states that he has met sheepmen who tell him that when they recognize an animal as affected with gid they forward it to the feeding point for market if they have a shipment about that time.

Dr. R. H. Treacy of this Bureau reports under date of June 5, 1907, a list of 11 flocks in Montana where gid, shown by the presence of cysts in the brain, was reported by Doctors Stauffer, Nutting, and Cary. According to Doctor Treacy, the sheepmen have been classing the trouble as loco, poison weed, water on the brain, grubs in the head, etc., and have paid no attention to destroying the dead animals. This fact, together with the statement of Doctor Stauffer in his letter of February 25, 1908, to Doctor Treacy, that certain sheepmen would not subject their dogs to vermifuge treatment because they were using the dogs, shows a condition of affairs which must make for the spread of gid in Montana. Two other factors in the spread of gid are mentioned by Doctor Cary in a letter to Doctor Treacy under date of April 9, 1908. One is the habit of some sheepmen picking up a dog wherever they can find one. The other is the "floater" band, or wandering band of sheep. In the latter connection he states:

> In the spring of 1907 a giddy band of "floaters" from Flatwillow country trailed along the northern boundary of the Crow Reservation, several of the lambs dying as they passed through the Blue Creek country 9 miles south of Billings, and I believe it was through this band that the Arthur Milne band in Blue Creek became affected this spring. * * * The Milne lambs were raised in the Blue Creek country, and gid has never been known there till this spring.

A discussion of the existing neglect of prophylactic measures against gid in the western part of the United States has been given by the writer in a bureau article. (See Hall, 1910*a*.)

Specimens of *Cœnurus cerebralis* from the brains of giddy sheep were collected by Professor Cooley January 5, 1904, Doctor McClure in May, 1906, Doctor Cary April 20, 1907, Doctor Davison December 21, 1907, Doctor Stauffer in January, 1908, and Doctor Peck July 11, 1908.

Doctor Stauffer also furnished a map of Chouteau County, Mont., showing the distribution of gid in that county. Doctor Treacy has prepared a map of the State of Montana showing the distribution of gid in that State during the spring of 1908. From these maps, from correspondence, and from information obtained during a personal investigation of gid in Montana during the spring of 1910, the map given here as figure 1 has been compiled. The infected areas shown by Doctor Treacy are indicated by solid blocks. Other infected areas where gid has occurred at some time during the period from 1898 to 1910, inclusive, are indicated by hollow blocks. The area where the continued recurrence of gid shows that the range is infected is indicated by shading. This area is 400 miles long and in places is 200 miles wide. During the personal investigation referred to above, evidence was obtained showing that cases of gid occurring outside of the infected area indicated on the map had probably been imported from the infected area. It will be seen from the map that gid has occurred in Teton, Chouteau, Valley, Cascade, Fergus, Gallatin, and Yellowstone counties. The first four and probably northern Dawson are infected ranges.

Montana's 5,747,000 sheep, representing, according to the Bureau of Statistics[a] of the United States Department of Agriculture, a value of $24,137,000 on January 1, 1910, are threatened by the presence of a disease which has become enzootic over a large part of the

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[a] Crop Reporter, U. S. Department of Agriculture, vol. 12, no. 2, February, 1910.

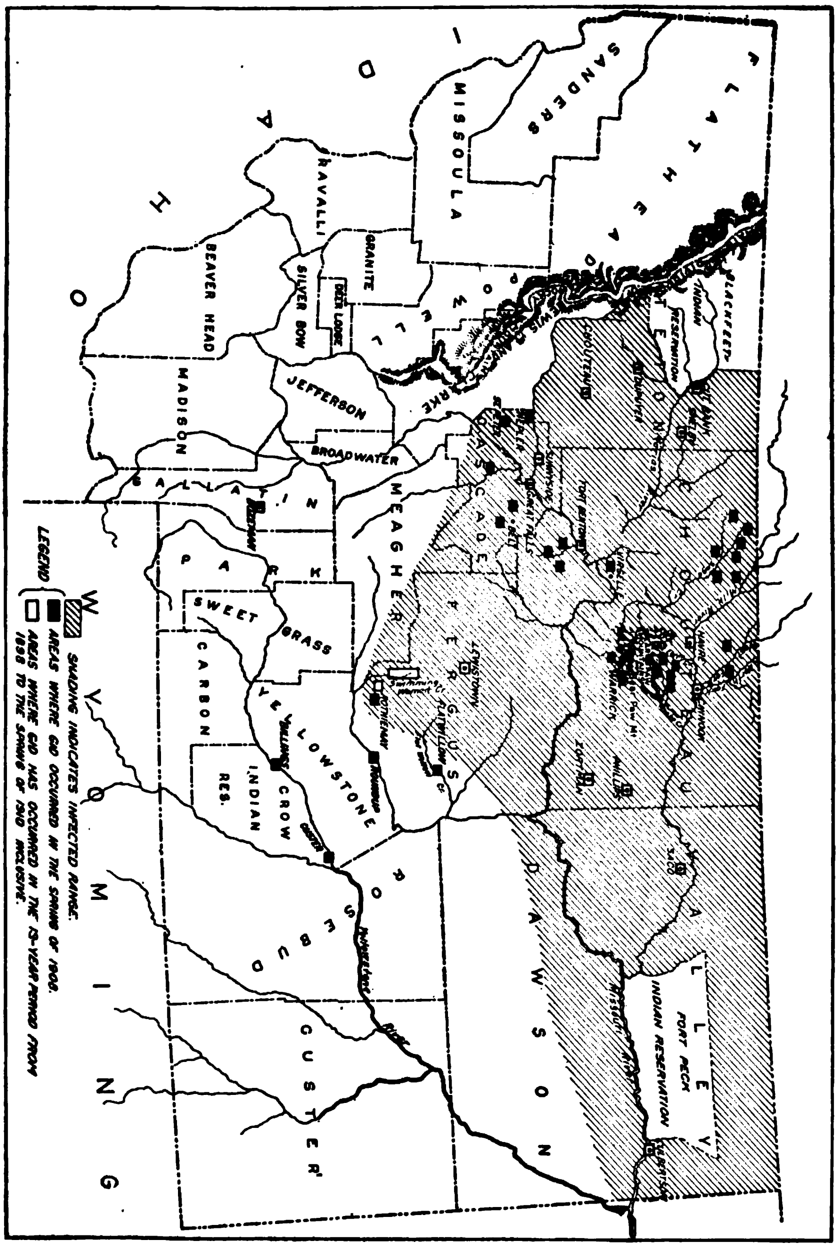

FIG. 1.—Map of Montana, showing distribution of gid in sheep.

State, and which in recent years has exacted toll in increasing amounts from the flocks. Such a condition necessarily exposes the flocks of neighboring States to the danger of infection carried from Montana by dogs or possibly by wild carnivora or in shipments of sheep. In view of the unsuccessful efforts of European countries to eradicate gid in over half a century of educated effort, and in view of the increase and spread of the disease in Montana in the last decade, it is to be hoped that the importance of attempting the eradication of this disease will soon be realized.

The first authentic instance of gid in the eastern United States occurred in 1909, and the first account of it was given by Doctor Law in a paper read before the New York State Veterinary Medical Society in August, 1909. The outbreak was reported by Taylor and Boynton (1910a), who found it in a flock of sheep about 40 miles from Ithaca. They discovered the gid parasite in the brain and claim to have raised one specimen of the adult tapeworm in a dog by feeding a cœnurus to it. They believed that they found the source of the disease in two collies imported from Scotland to the farm where the disease occurred. The adult parasite was apparently not sought for in the dogs. In a footnote they state that Dr. Charles Linch investigated an outbreak of disease among sheep in New York in the spring of 1909 and reported that it was gid, but did not report finding the parasite.

Melvin (1910$\alpha$) has called attention to the fact that Taylor and Boynton have overlooked a number of articles when they state:

> In a careful search of the literature we have failed to find any authentic report of a positively identified case of the disease having appeared in the United States.

Subsequently, Taylor and Boynton (1910$\beta$) have modified this statement, making it refer only to New York State.

The occurrence of certain, probable, and doubtful cases of gid in the United States is indicated in the following tabular statement.

*List of occurrences of Multiceps multiceps recorded from the United States.*

| Locality. | Author. | Date. | Notes and comments. |
|---|---|---|---|
| New York (?) | Livingston | 1809α | Three cases; probably meningitis, not gid. |
| United States (?) | Leidy | 1856a and b | Parasite observed; place not stated. |
| Do | McClure | 1870α | Do. |
| United States | Verrill | 1870d | States that gid occurs in United States. |
| New York and elsewhere. | Tellor | 1879a | Do. |
| Tennessee | Crutchfield | 1880α | Claims to have lost sheep from gid; no symptoms or post-mortem records. |
| United States | Stewart | 1880a | States that gid occurs in United States. |
| Eastern United States | Powers | 1887α | Claims to have cured, but not seen gid. |
| United States | Curtice | 1890c | States that gid occurs in United States. |
| Colorado | do | 1892g | Adult from dog; Curtice doubts correctness; I find it incorrect. |
| United States | Veterinary editor, American Sheep Breeder. | 1895α | Imported Shropshire; symptoms and post-mortem indicate gid. |
| Do | do | 1895β | One case; characteristic symptoms. |
| Nebraska | Ward | 1896b | Adult from dog; Stiles (1898a), on examination, makes this *T. serialis*. Accepted by Ward (1897b) from correspondence. |
| United States | Veterinary editor, American Sheep Breeder. | 1897β | One case; characteristic symptoms. |
| Montana | Knowles | 1897α | Notes inquiries in regard to gid. Dr. Knowles saw cases in 1897. |
| Minnesota | Stiles | 1898a | One case in horse under skin; Stiles thinks this may be *C. serialis*; doubtful; case previously noted by Railliet (1893a) from correspondence. |
| Iowa | Wallace | 1900a | One case; symptoms not characteristic. |
| Minnesota | Shaw | 1901a | States that gid occurs in United States. |
| Montana | Veterinary editor, American Sheep Breeder. | 1901γ and δ | Several cases; symptoms and post-mortem show gid unmistakably. |
| Colorado | do | 1901δ | States that gid occurs in United States; Curtice wrongly quoted as authority. |
| United States | do | 1901δ | Seven cases operated on by author. |
| Illinois | Veterinary editor, American Shepherd's Bulletin. | 1902α | One case; characteristic symptoms. |
| Nevada | Veterinary editor, American Sheep Breeder. | 1903α | Several cases; symptoms and post-mortem show gid unmistakably. |
| Kansas | do | 1903β | Several cases; characteristic symptoms. |
| Iowa | do | 1903γ | One case; characteristic symptoms. |
| Utah and elsewhere | Veterinary editor, American Shepherd's Bulletin. | 1903α | States that gid occurs in United States. |
| Michigan | do | 1903β | Two imported rams; characteristic symptoms. |
| United States | do | 1903γ | One case; "bag of water" on brain. |
| Montana | Ransom | 1905d | Several cases in 1904; parasite found and studied. |
| Missouri | Veterinary editor, American Sheep Breeder. | 1905α | Several cases; characteristic symptoms. |
| Kansas | do | 1905β | Several cases; symptoms not characteristic. |
| Ohio | do | 1905γ | Two cases; symptoms and post-mortems show gid; had lost sheep thus before. |
| Colorado | do | 1905δ | Few cases; symptoms not characteristic. |
| United States | do | 1905ε | States that gid occurs in United States; in answer to some letters. |
| Indian Territory | do | 1905ζ | Several cases; symptoms and post-mortems show gid. |
| Missouri | Luckey | 1908α | States that gid occurs in United States. |
| United States | Veterinary editor, American Sheep Breeder. | 1908α | Do. |
| Iowa | do | 1908β | One case; symptoms not characteristic. |
| Montana and Washington, D. C. | Hall | 1909α | Two natural and one experimental infections; first record in this country of adult worm produced by feeding larva. |
| New York | Taylor and Boynton. | 1910α | Several cases; symptoms and post-mortem show gid. |
| Montana | Hall | 1910β | This article. |

The following list of cases occurring in the United States and not previously recorded is compiled from correspondence as given:

*List of occurrences of Multiceps multiceps in the United States recorded here for the first time.*

| Locality. | Letter. | Notes and dates. |
|---|---|---|
| Shelby, Mont. | Dr. McClure to Dr. Melvin, July 18, 1906. | Sun River Land and Live Stock Co.; 250 out of 10,000; 1906; 1 case shipped to Washington, D. C., died en route. |
| Chouteau County, Mont. | Dr. McClure to Dr. Melvin, Sept. 3, 1906. | Cowell flock; 40 to 60 out of 2,000; many years. |
| Do. | Dr. McClure to Dr. Melvin, Oct. 15, 1906. | Cowell flock; 15 to 30 cases; almost every year. |
| Do. | do. | McDonald flock; 15 to 20 cases some years. |
| Sunnyside, Cascade County, Mont. | do. | Sun River Land and Live Stock Co.; 200 out of 10,000; 1905. |
| Zortman, Chouteau County, Mont. | do. | Whitcomb flock; 30 out of 4,000; 1898. |
| Phillips, Mont. | do. | Phillips flock; 15 out of 15,000; 1906. |
| Ohio. | Dr. Ransom to Dr. McClure, Oct. 24, 1906. | Rambouillet sheepmen claim to have had several cases in imported and at least one case in native sheep. |
| Montana. | Dr. McClure to Dr. Melvin, Dec. 5, 1906. | Phillips flock; 2 or 3 at date of writing. |
| Rothiemay, Mont. | Dr. Cary to Dr. Treacy, Apr. 20, 1907. | Pirrie flock; 250 to 300; 1907; parasite found in 3 of 4 examined. |
| Chouteau, Mont. | Dr. Nutting to Dr. Treacy, April, 1907. | McDonald flock; 125 dead at date of writing. |
| Flatwillow country, Fergus County, Mont. | Dr. Cary to Dr. Treacy, May 21, 1907. | Infected country; 1907. |
| Swimming Woman country, Fergus County, Mont. | do. | Do. |
| Yellowstone County, Mont. | do. | Sheep from Flatwillow country and probably infected there. |
| Chinook, Mont. | Dr. McClure to Dr. Melvin, June 5, 1907. | In Blackwood, Taylor, Sprinkle, Sprinkle Bros., and McCann flocks; 1907; reported by Dr. Stauffer. |
| Saco, Mont. | do. | Rieder flock; 1907; reported by Dr. Stauffer. |
| Cut Bank, Mont. | do. | Town flock; 1907; reported by Dr. Stauffer. |
| Chouteau County, Mont. | do. | McDonald flock; 1907; reported by Dr. Nutting. |
| Dupuyer, Mont. | do. | Leech flock; 1907; reported by Dr. Nutting. |
| Huntley, Mont. | do. | Green flock; 1907; reported by Dr. Cary. |
| Rothiemay, Mont. | do. | Pirrie flock; 1907; reported by Dr. Cary. |
| South Dakota. | Dr. Ransom to Dr. Hickman, July 2, 1907. | One case in imported ram. |
| Teton County, Mont. | Dr. Davison to Dr. Melvin, Dec. 21, 1907. | McDonald flock; several cases at date of writing; parasite found; 10 per cent lost the winter before. |
| Sage Creek, Mont. | Dr. Stauffer to Dr. Treacy, Feb. 25, 1908. | Sprague and Lavid flocks; 1908. |
| Bear Paw Mountains, Mont. | do. | L. Sprinkle, C. Sprinkle, and Taylor flocks; 1907 and 1908. |
| Benton, Mont. | do. | Northwestern Live Stock Co.; 1908. |
| Virgelle, Mont. | do. | Blankenbaker flock; 1908. |
| Chinook, Mont. | do. | One case; 1907. |
| Billings, Mont. | Roy Stebbins to Dr. Melvin, Feb. 27, 1908. | Ewes affected; not clearly gid. |
| Swimming Woman country, Flatwillow country, Musselshell country, Custer Station, and Blue Creek country. | Dr. Cary to Dr. Treacy, Apr. 9, 1908. | Most of these giddy bands seem to have originated in the Flatwillow country. |
| Conrad, Mont. | Dr. Peck to Dr. Melvin, July 8, 1908. | One sheep shipped to Washington, D. C. |
| Fort Benton, Mont. | Dr. Peck to Dr. Melvin, July 13, 1908. | Parasite forwarded to Washington, D. C. |
| Gildford, Chouteau County, Mont. | Dr. Stauffer to Dr. Melvin, Feb. 5, 1909. | Two sheep shipped to Washington, D. C. |
| Willow Springs, Mo. | Dr. Luckey to the writer, July 21, 1909. | Symptoms of gid in goats; date not given. |
| Waverly, Iowa. | Dr. McHenry to Dr. Melvin, June 14, 1910. | Two cases, one showing cyst on post-mortem examination. |

Some discrepancies will be noted in the above figures. No attempt has been made to ascertain which are correct. Dates of occurrences must also be taken with some regard for the fact that a record of gid by one or more observers as occurring in two consecutive years may not necessarily be a record of two outbreaks but merely a record of one outbreak running through the winter of one year into the spring of the following year.

Giddy sheep have been sent in to this laboratory from Montana on four occasions, two sheep being sent in May, 1907; one in July, 1908; two, already noted as recorded by Hall (1909*a*), in February, 1909; and one in May, 1910. In an earlier shipment in July, 1906, the one sheep sent died en route.

Both the adult and larval *Multiceps multiceps* have been produced in this laboratory at Washington, D. C., and at Bethesda, Md., by feeding experiments in cases other than those noted by Hall (1909*a*) in an earlier paper.

From the foregoing it seems certain that the gid parasite was observed in this country at least as early as 1901. It does not seem likely that the many claims made for its occurrence earlier than this are entirely unfounded. During an investigation of gid in Montana in the spring of 1910, the writer met a number of sheepmen who claimed to have had their first losses from gid some time between the years 1885 and 1890. These men have been acquainted with the disease ever since and still have it in their flocks, so that there is no reasonable doubt as to gid having occurred in this country previous to 1890. Certainly it now has a foothold in this country.

## GID IN CANADA.

The presence of gid in either the United States or in Canada must necessarily be of interest to the other of the two countries, owing to the possibility of the disease being carried across the border by dogs or wild carnivora or in shipments of sheep. In the course of a correspondence with this Bureau relative to gid, Dr. J. G. Rutherford, the veterinary director-general of Canada, undertook to find out whether gid had been imported into Canada by making inquiry of sheep breeders and dealers. From a synoptical statement of the replies made by thirteen dealers it appears that eleven have never seen the disease in their flocks, and Doctor Rutherford himself states, in a letter of October 8, 1909:

> During many years' practice, I have, personally, never seen the disease in Canada, although I was quite familiar with it in Scotland when a young man. I have never heard the disease mentioned by Canadian veterinarians, although, as you are aware, this is no proof of its nonexistence in the country, as the members of our profession are seldom called upon to treat sheep.

Of the two dealers who had seen the disease, F. H. Neil, of Lucan, Ontario, "has had no trouble with gid parasite for a number of years. Has seen some flocks affected in both Canada and the United States, but does not specify where."

The other dealer, J. H. Patrick, of Ilderton, Ontario, "has had no trouble with this parasite the last few years; previously when importing sheep in large numbers experienced considerable loss, which he attributed to this cause."

From a scientific standpoint, the data given above do not justify a positive record of the gid parasite from Canada, and if the disease exists there at all it seems from the above evidence to be comparatively unimportant. At the same time, the presence of gid in northern Montana would constitute a ready source of infection for sheep in Canadian territory.

## THE HOSTS AND OCCURRENCES OF THE LARVAL MULTICEPS MULTICEPS.

In compiling the following list of hosts, an attempt has been made to put them on an objective basis so far as possible. A list of certain or probable hosts has been compiled for those cases where *Multiceps multiceps*, or what appears to have been *M. multiceps*, has been found at least once in the host in question. A list of erroneous records has been compiled for cases where there is certainly an error in the record or in the finding. A third list of doubtful forms seems to be the only proper place for cases where the evidence is inadequate for the acceptance or rejection of the record.

In the first list given below, only those records of occurrences in sheep and cattle which are of historic interest or which show geographic or time distribution are given, as the former are the usual and the latter the very common hosts of the parasite. In the other cases there are included only those where the presence of a cœnurus has been shown at least once for that host, assuming it as probable from the evidence at hand that the cœnurus in question was *Multiceps multiceps*.

*List of certain or probable occurrences of the larval Multiceps multiceps.*

| Host. | Locality. | Authority. | Notes and comments. |
|---|---|---|---|
| Sheep | Greece | Hippocrates 1825*a* | Probable cases 460-375 B. C. |
| Goat | do | do | Do. |
| Sheep | Germany | Rolfinck 1656a | |
| Do | Switzerland | Wepfer 1658*a* | |
| Cattle | do | do | |
| Sheep | Germany | Scultetus 1672a | Date of first certain case 1634. |
| Cattle | Germany (?) | Brunner 1694*a* | According to Küchenmeister (1880a). |
| Do | "Berovia"<br>"Gurtwillae" | Wepfer 1724*a* | |
| Sheep | Germany | Leske 1780a | First recognized as a cestode parasite. |
| Do | do | Goeze 1780a | Independently recognized as a parasite. |
| Do | Italy | Fontana 1784a | |
| Cattle | do | do | |
| Sheep | Germany | Schrank 1788a | |
| Cattle | do | do | |
| Chamois | Alps | Retzius 1790a | At least one case. |
| Sheep | England | Moorcroft 1792a | Claimed to occur in France and Italy also. |
| Cattle | do | do | |
| African antelope | Not given | Rudolphi 1808a | Accepted here on basis of subsequent findings. |

*List of certain or probable occurrences of the larval Multiceps multiceps*—Continued.

| Host. | Locality. | Authority. | Notes and comments. |
|---|---|---|---|
| Sheep | France | Bosc 1816a |  |
| Horse | (?) | Bousset 1822a | According to Gurlt (1831a). |
| Do | (?) | Hofacker 1823a | According to Numan (1850b). |
| Chamois | Paris, France | De Blainville 1824a |  |
| Sheep | France | Yvart 1827a | First record from spinal canal, according to Braun (1894a). |
| Do | do | Dupuy 1831a | From spinal canal. |
| Horse | (?) | Frenzel (Date?) | According to Gurlt (1831a) and Numan (1850b). |
| Do | England | Youatt 1834b | "Hydatid" in septum lucidum; symptoms given. |
| St. Domingo goat | do | Youatt 1836c | "Hydatid" considered here as cœnurus on basis of subsequent findings. |
| Sheep | Germany | Pluskal 1844a | Indefinite number of spinal cases. |
| Do | Austria | do |  |
| Do | Ireland | Bellingham 1844a |  |
| Goat | Germany | Klencke 1844a |  |
| Mouflon | Montpellier, France | Gervais 1847b | One case. |
| Horse | (?) | Ammon (?) | According to Numan (1850b). |
| Sheep | (?) | Störig (Date?) | Found it twice in the medulla oblongata, according to Numan (1850b). |
| Do | Holland | Numan 1850b | Among others, one had cœnurus in cerebrum, medulla oblongata, and in spinal cord. |
| Angora goat | do | do | Cœnurus is figured. |
| Cattle | Kempton, [Bavaria?]. | Hering 1852a | Occurred in 1850–51. |
| Sheep | Germany | Hagmaier 1853a | In spinal canal. |
| Antelope | (?) | Jacques and Lafosse 1854b. |  |
| Goat | (?) | do |  |
| Sheep | Scotland | McCall 1857a |  |
| Do | France | Reynal 1857a |  |
| Cattle | do | do |  |
| Sheep | Alfort, France | Valenciennes 1857a | In spinal cord and brain; sent by Delafond. |
| Horse | Vienna, Austria | Spinola 1858b | In spinal cord; specimen in veterinary school. |
| Sheep | Germany | do | In spinal cord. |
| Goat | Toulouse, France | Baillet 1859b | One certain and 1 possible infection of 4 experiment animals. |
| Gazelle | do | do |  |
| Sheep | Warschau | Leisering 1859a | Eichler's subcutaneous specimen; found to be cœnurus by Eichler, Leisering, and Zenker. |
| Do | Germany | Leisering 1862a | Von Nathusius' subcutaneous specimen; Eichler's specimen noted again. |
| Gazelle (*Antilope dorcas*). | do | do | One case in a zoological park. |
| Horse | Prussia | Esse et al. 1863a; Keiper et al. 1864.a | One case; accepted on symptoms and in view of other cases. |
| Sheep | Iceland | Krabbe 1864h | Disease often seen here; accepted on Krabbe's finding of adult worm in dogs. |
| Cattle | do | do | Rare; accepted as above. |
| Sheep | Denmark | do | Claimed to occur; accepted as above. |
| Cattle | do | do | Do. |
| Do | England | Cooper 1865a | Three cases. |
| Chamois | Germany | Frauenfeld 1868a | Do. |
| Sheep | Vienna, Austria | Bénion 1874a | Several spinal cases seen by Röll. |
| Sheep | Germany | Müller 1877a | One case with cœnurus in spinal cord; 1 in medulla oblongata. |
| Antelope (*Bubalis sp.*). | Lyon, France | Bertolus and Chauveau 1879a. | Host from Africa. |
| Sheep | South Australia | Dixon 1883a |  |
| Do | Sardinia | Parona 1884a |  |
| Horse | Culm, Germany | Schwanefeld 1885a | Contained one-sixteenth of a liter of fluid. |
| Sheep | Buenos Ayres, Argentine Republic. | Wernicke 1886a |  |
| *Hipootragus equinus* (?). | Germany | Rabe 1889a | Host from South Africa; in brain, thyroid, lymph glands, and musculature. |
| Sheep | Montana, U. S | Vet. Ed. Amer. Sheep Breeder 1901γ and δ. | Accepted on symptoms and post-mortem findings. |
| Do | New Zealand | Gilruth 1902a |  |
| Goat | Cape Colony | Buckley 1904a | Several cases; accepted on symptoms and post-mortem findings. |
| Cow | do | Robinson 1905a | One case. |

*List of certain or probable occurrences of the larval Multiceps multiceps*—Continued.

| Host. | Locality. | Authority. | Notes and comments. |
|---|---|---|---|
| Cattle | France | Leblanc and Freger 1907*a*. | One case. |
| Chamois | Germany | Roth 1907c | Do. |
| Cattle | England | Pollock 1908*a*. | |
| Horse | Shetland | White 1909a | One case; symptoms of gid and recovery of parasite by operation. |
| Cow | Germany | Pfab 1909*a* | The only record found of the parasite from the vertebral canal in this host. |
| Sheep | England | Lloyd 1909*a* | |
| Cattle | Italy | Vicariotto 1909a | |
| Sheep | Montana and Washington, D. C. | Hall 1909*a* | |
| Goat | Missouri, U. S | Doctor Luckey in letter of July 21, 1909. | From personal correspondence with Doctor Luckey already noted. |
| Cow | Germany | Borstelmann 1910*a* | Bladderworm the size of pigeon egg in medulla oblongata; probably *M. multiceps* from size and location. |
| Cattle | do | Pfab 1910*a* | Fifty-eight operations from 1903 to 1909, inclusive; additional cysts found in the medulla oblongata in 3 cases. |
| Sheep | German Southwest Africa. | Scheben 1910*a* | |

A reference by title only to an article by Gough (1909*a*) on "A Cœnurus in the Duiker" can not be verified at this time, as the article is not yet available. The article is referred to here on the likelihood of a cœnurus from the duiker antelope being the gid parasite.

In the foregoing list the sheep, cow, goat, horse, chamois, mouflon, gazelle, and some antelope forms—given as antelope, African antelope, *Bubalis sp.* and *Hippotragus equinus* (?)—are accepted as hosts of *Multiceps multiceps*.

The parasite is recorded from sheep in Greece, Germany, Switzerland, England, France, Italy, Ireland, Holland, Scotland, Austria, Denmark, Iceland, Argentine Republic, Sardinia, South Australia, New Zealand, German Southwest Africa, and the United States. Its presence is claimed or implied, by local names for gid or otherwise, in Hungary by Küchenmeister (1853e) and Cobbold (1867o), in Cape Colony by Hellier (1894a) and Hutcheon (1904*a*), in Chile and Spain by Monfallet (1899a), and in Shetland by White (1909*a*).

It is recorded from cattle in Switzerland, Germany, England, Italy, France, Iceland, Denmark, and Cape Colony.

It is recorded and figured from the goat in Holland by Numan (1850b); it was experimentally produced in this host in France at least once and possibly twice by Baillet (1859b); the characteristic symptoms and post-mortem findings are recorded for several cases in Cape Colony by Buckley (1904*a*); and on the strength of these records the following have been accepted: Jacques and Lafosse's (1854b) case, Youatt's (1836*a*) "hydatid" from the brain of a goat with symptoms of gid, Klencke's (1844a) record from Germany, Hippocrates's (1825*a*) necessarily uncertain record from Greece, and Doctor Luckey's cases recorded here from the United States. Klencke claims to have produced the cœnurus by an absurd inoculation experiment, but this host record may be accepted in view of the possibility that he inoculated a goat already infected with gid.

Doctor Luckey's cases are accepted on the objective grounds that the cases seemed to be gid and that the parasite is known from that host and has been found in this country. Baillet (1859b) says that gid has often been seen in goats by veterinarians, but does not add any particulars.

Spinola (1858b) states that the veterinary school at Vienna had a specimen of the gid parasite taken from the spinal cord of a horse. Esse and his associates (1863*α*) and Keiper and his associates (1863*α* and 1864*α*) found a parasite in the brain of a horse in Prussia, and on the strength of the symptoms concluded that it was a cœnurus, but they apparently did not study the parasite to see what it was. Schwanefeld (1885a) states that he found a cœnurus containing one-sixteenth of a liter of fluid in the brain of a horse in Germany. Youatt (1834*β*) saw a horse that showed symptoms of staggering; post-mortem examination disclosed a "hydatid" in the septum lucidum. White (1909a) operated on a horse that showed symptoms of gid and extracted a cyst from the brain. On the combined evidence the above cases are accepted, as well as those of Ammon, Bousset, Frenzel, and Hofacker as given by Gurlt (1831a) and Numan (1850b), which cases are covered in articles not at present available.

*Multiceps multiceps* is recorded from the chamois in Switzerland by Retzius (1790a), in France by De Blainville (1824a), in three cases in Germany by Frauenfeld (1868a), and in one case by Roth (1907c), a total of six cases. Frauenfeld also states that the royal head forester had noted several cases of gid in the chamois and that the disease is well known to old chamois hunters.

The parasite has been found in the gazelle in France by Baillet (1859b) and in Germany by Leisering (1862a).

It has been found in the antelope by Jacques and Lafosse (1854b), in *Hippotragus equinus* (?) by Rabe (1889a), in *Bubalis sp.* by Bertolus and Chauveau (1879a), and in an African antelope by Rudolphi (1808a).

In Rabe's case the host had only been in Germany fourteen days after its arrival from Africa, and Leisering's host animal was from a zoological park; the host noted by Bertolus and Chauveau had been shipped from Africa to France, and Rudolphi's antelope is specified as African. Gough's (1909*α*) cœnurus, alluded to on page 32 is another case of a cœnurus in an African antelope. These facts seem to indicate that the gid parasite is not uncommon among the Bovidæ of Africa. Nor is this an unreasonable supposition. Varieties of native sheep and species of antelope are so distributed throughout Asia, Africa, and Europe that there is practically no break in the geographic distribution of host species between the European countries known to be infected and the Cape of Good Hope, where it appears from the records of Hellier (1894a), Buckley (1904*α*), Robinson (1905a), and Robertson (1908*α*) that the disease also exists. The transmission of the parasite across this area, if indeed it was not originally distributed from Egypt, or the valley of the Euphrates, would be a simple matter for the flocks of nomadic shepherds or individual hosts of the adult or larval parasite. Scheben (1910*a*) states that gid is a trouble of long standing in German Southwest Africa. The increasing interest in the parasite fauna of Africa ought to result in additional light being thrown on this subject.

*Multiceps multiceps* has been recorded once from the mouflon in France by Gervais (1847b). Schrank's (1788a) statement that it occurs in the mouflon is without any record of authority or of personal observation.

The above list shows records of the occurrence of *Multiceps multiceps* more than eight times in the spinal cord of sheep, in one case with a simultaneous infection of the brain, and in one case with simultaneous infection of the brain and medulla oblongata. The parasite is twice recorded from the medulla oblongata alone in the sheep with a total of three cases. It must be much more common in these locations than records of cases show, as Frenzel (1794a) stated over a century ago that the parasite occurs in the brain, medulla oblongata, and spinal cord. It is recorded from the subcutaneous tissue of the sheep twice, from the spinal cord of the horse once, from the spinal cord of the cow once, from the medulla oblongata of the cow four times, and from the brain, thyroid, lymph glands, and musculature of the gazelle once.

If from the above list of certain and probable occurrences there were selected those cases where it is certain that the parasite was *Multiceps multiceps*, on the basis of description, figures, and feeding experiments, the certain hosts would be limited to the sheep, cow, and goat.

In the following list are shown those cases where a record is based on data which I regard as inadequate, or where the author himself has considered the case doubtful, or where both these things are true:

*List of doubtful cases of the occurrence of the larval Multiceps multiceps.*

| Host. | Locality. | Authority. | Notes and comments. |
|---|---|---|---|
| Reindeer (*Cervus tarandus*). | Lapland | Hoffberg 1759a | Symptoms resemble gid; so accepted by Braun (1894a). |
| Giraffe (*Camelopardalis giraffa*). | Not given | Rudolphi 1804a, 1810a. | |
| Horse | do | Rudolphi 1808a | Statement that hydatids are rare in the brain of the horse. |
| Do | do | Gurlt 1831a | Brain and spinal cord. |
| Roe deer (*Cervus capreolus*). | do | Barthelemy 1839a | Mere statement; accepted by Diesing (1850a). |
| Sheep | Germany | Jacobi 1882a | Entire flock afflicted with spinal gid. |
| Pig | Finland | Kolster 1893a | In heart. |
| Horse | United States | Stiles 1898a | Subcutaneous. |
| Dog | Italy | Guerrini 1909a | Given in list of museum specimens. |

The above list shows that it is doubtful whether the reindeer, giraffe, roe deer, pig, and dog can be considered as hosts of *Multiceps multiceps*.

In the historical sketch (p. 10) the necessity for considering the reindeer a doubtful host of *Multiceps multiceps* has already been shown. It is true that Diesing (1850a) lists the parasite from this host, crediting the observation to Retzius, but as a matter of fact Retzius (1790a) lists the parasite from *Capra rupicapra,* the chamois, and not from the reindeer.

Rudolphi (1804a) states that in conversation with Le Vaillant, the latter told him that he had found worms in the brain of the gazelle and the giraffe. Later, Rudolphi (1810a) lists these as "*?Cœnurus cerebralis*" from the gazelle, and "*?Cœnurus*" from *Camelopardalis giraffa,* showing that he himself felt very doubtful of this last case. In view of the fact that no one has previously or since recorded a cœnurus from this host, and that Rudolphi (1819a) later omits the giraffe from his list of hosts of this parasite, and in view of the fact that the giraffe's habit of feeding largely on high-growing foliage renders it little likely to have its food contaminated by the feces of the known hosts of the adult *Multiceps multiceps,* we must consider this record of Le Vaillant's finding very doubtful.

Rudolphi's (1808a) bare statement that hydatids in the brain of the horse were rare, together with his failure to list his *Cœnurus cerebralis* from this host in his later work of 1810, leaves it extremely doubtful whether he knew of any cases of the occurrence of *C. cerebralis* in this host.

Gurlt (1831a), in a list of hosts of *Multiceps multiceps,* lists it from the horse, specifying the brain and spinal cord as locations. As he gives no record of cases and no authority for this statement, it seems likely that he was reasoning the possibility of this from the occurrence of the parasite in both locations in the sheep.

The acceptance of the roe deer, *Cervus capreolus,* as a host of *Multiceps multiceps* by Diesing (1850a) and by subsequent writers is based by Diesing and by such writers as take the trouble to cite an authority on Barthelemy (1839*a*). Barthelemy states that gid occurs in sheep, in the roe deer, and in other animals. He does not claim to have seen the parasite in the roe deer, nor does he cite any one who has, hence his statement, though very plausible, is not convincing, and this record must also be held doubtful.

According to Jacobi (1882*a*), in a flock of 400 yearling lambs, 186 died with cœnuri in various parts of the spinal cord, but no cœnuri were found in the brain. The correctness of this statement seems questionable. That cœnuri should be found in the spinal cord in a great number of sheep would be surprising; that none should be found in the brain at the same time is scarcely to be believed. Possibly the disease in question was hydro-rhachitis and serum accumulations in various parts of the cord were mistaken for cœnuri.

Kolster (1893a) found several vesicles, each having several heads, under the pericardium of a pig. He could not decide whether it was the larva of *Tænia cœnurus* or of some other *Tænia* having a cœnurus larva. I consider this case extremely doubtful. If *Multiceps multiceps* could develop in the pig, it seems likely that it would not be altogether uncommon, and hence would have been reported heretofore. Furthermore, the location is an unlikely one for this parasite. As the specimen in question does not seem to have had the study necessary for an identification, we are compelled to include the pig among the doubtful hosts of *Multiceps multiceps*.

In discussing gid in the United States, we have already considered Stiles's (1898a) record of subcutaneous cœnurus in the horse.

Guerrini (1909*α*), in a list of the parasite specimens in the collection of the veterinary college at Bologna, lists *Cœnurus cerebralis* Rud. from *Bos taurus* (meninges) and *Canis familiaris* (meninges). The adult worm, *Tænia cœnurus* Küchenm., is also listed from *Canis familiaris* (intestinum). Such a record of *Cœnurus cerebralis* from the meninges of the dog must ncessarily be looked upon with doubt. When an extremely unusual or unlikely thing is recorded, the acceptance of the record must depend upon the evidence. The reliability of the collector, the accuracy of the person identifying the specimen, the features on which the identification was made, and the validity of the label, are all matters which should be made known. No evidence is furnished in this case, and hence the record of such a parasite in the dog can not be accepted without reservation.

In the opinion of the writer all records of the giraffe, the roe deer, the pig, and the dog as hosts of the larval *Multiceps multiceps* should be thrown out, as they are all probably erroneous.

The following list includes those cases where the records show undoubted errors.

*List of the erroneous records of the occurrence of the larval Multiceps multiceps.*

| Host. | Locality. | Authority. | Notes and comments. |
|---|---|---|---|
| Man | Not given | Rolfinck 1656a | |
| Dog | England | Moorcroft 1792a | |
| Rabbit (?) | Not given | Lænnec 1804a | |
| Rabbit | do | Cloquet 1818a | |
| Do | France | Leblond 1837a | |
| Man | Germany | Klencke 1844a | Claims to have seen a case. |
| Dog | do | do | Produced by injection of rotten cœnurus in veins. |
| Rabbit | do | do | Produced by inoculation of rotten cœnurus on brain. |
| Cat | do | Numan 1850b | Misprint or based on mistranslation. |
| Camel | Not given | do | Based on Aran (1841a). |
| Reindeer (*Cervus tarandus*). | do | Diesing 1850a | Based on Retzius (1790a). |
| Camel (*Camelus dromedarius*). | do | Diesing 1850a et al. | Based on De Blainville (1824a). |
| Rabbit | do | do | Based on Leblond (1837a). |
| "Ex *Ipalacis capensis*." | Port Natal | do | |
| Pig | Not given | Veterinarian 1855a | |
| Cow | do | Fuchs 1859a | In spinal cord. |
| *Spalax capensis* | Port Natal | Diesing 1864a | |
| Cow | Not given | Pagenstecher 1877a | Von Nathusius's subcutaneous specimen from sheep erroneously listed. |
| Do | do | Von Linstow 1878a | Subcutaneous; error as above. |
| Do | do | Moniez 1880a | Do. |

*List of the erroneous records of the occurrence of the larval Multiceps multiceps*—Cont'd.

| Host. | Locality. | Authority. | Notes and comments. |
|---|---|---|---|
| Cow | Not given | Leuckart 1886d | Same error as Pagenstecher (1877a) above. |
| Goose | do | Neumann 1888a | Based on Hering (1861*a*). |
| Cow | do | Railliet 1893a | Same error as Pagenstecher (1877a) above. |
| Horse | Germany | do | In eye; based on Heincke (1882a). |
| Sanbur (*Cervus unicolor*). | Not given | Hassall 1898a | In list. |
| Cow | do | Vaullegeard 1901a | In eye. |
| Antelope | do | do | Do. |
| Camel | do | Espejo y Del Rosal 1905β. | Based on Lafosse. |

The weight of evidence indicates that there are no certain, probable, or reasonably doubtful cases of the occurrence of *Multiceps multiceps* in the larval state in man, the cat, rabbit, camel, sanbur, goose, or the hypothetical "*Ipalax capensis.*" It is also reasonably certain that Moorcroft (1792a) and Klencke (1844a) have erred in recording *Cœnurus* from the dog; that Retzius did not find a cœnurus in *Cervus tarandus*, as Diesing (1850a) credits him with doing; that the record of *Multiceps multiceps* from the spinal cord of the cow given by Fuchs (1859a) is not based on an actual case; that *M. multiceps* has not been found in a subcutaneous location in the same host as Pagenstecher (1877a), Von Linstow (1878a), Moniez (1880a), Leuckart (1886d), and Railliet (1893a) give it; that Heincke's (1882a) parasite from the eye of the horse was not a cœnurus as Railliet (1893a) states, and that *M. multiceps* is not known from the eye of the cow and of the antelope, as Vaullegeard (1901a) states.

Rolfinck (1856a) refers to a vertigo caused by vesicles full of water and serous humor in the brain of sheep and of man. Undoubtedly he refers to gid and its parasite in sheep, but the vertigo referred to in man has been found to be due to *Cysticercus cellulosæ* and *Echinococcus granulosus* in those cases where the most competent scientists have investigated the parasite. Klencke's (1844a) statement that he has seen a cœnurus in the brain of man does not of itself give sufficient data on which to reject the finding, but a study of Klencke's work, in which he claims to have repeatedly produced cœnurus in various hosts by inoculation of cœnurus particles, shows that his statements are not reliable, and for this reason his quite improbable claim of the occurrence of cœnurus in man is thrown out. Gervais and van Beneden (1859b) have stated that Klencke's statements do not merit confidence.

In his nomenclature of diseases of man, Bertillon (1903*α*) lists *Cœnure* under diseases of the digestive tract, and the Commission Internationale (1909*α*), in its revision of the same work, has retained this listing. As the records indicate, there are probably no cases of cœnurus in man. Whether such cases have occurred or not, there are no good grounds for listing cœnurus or cysticercus as intestinal parasites, as Bertillon and the commission have done.

Moorcroft (1792a) states that anatomists and, to a still greater extent, butchers and shepherds, have long known of collections of colorless fluid in thin capsules in the brain of sheep and cows, and adds: "They have been met with in dogs."

The larval cestodes of dogs include, according to various authors, *Cysticercus* and *Echinococcus*. Von Linstow (1889a) lists a *Cœnurus sp.* from the dog, attributing it to Pagenstecher, but Pagenstecher (1877a), in the reference cited, refers to a growth on the neck of *Myopotamus coypus*, which he says might have been a growth of a cystoid or colloid nature such as is found in dogs, but which he finds to be a cœnurus. Klencke (1844a) claims to have produced a cœnurus in the dog by injecting rotten cœnurus into its veins, a claim so absurd as to at once discredit his findings. Guerrini's (1909*a*) record of a museum specimen has already been mentioned as doubtful. There are, therefore, no adequate and reliable references to a cœnurus from the dog, and as it is on the face of it highly improbable that the larval *Multiceps multiceps* would occur in the dog, we may throw out Moorcroft's casual reference.

Læennec (1804a) states that the gid parasite occurs in the sheep, the cow, and perhaps in the rabbit. The last host is included on the basis of hunters' statements that they have seen gid in rabbits. Moniez (1880a) says he has seen such a case of gid in the rabbit, but it was not due to a cœnurus, and Læennec admits that no one had ever seen the parasite in such cases.

Cloquet (1818a), in an article which appears to be an abstract of Læennec (1804a or 1812a), has made a positive statement of Læennec's tentative inclusion of the rabbit as a host of the gid parasite.

Leblond (1837a) notes that Læennec (1812a) did not know of any vesicular worms from the brain of the rabbit, and describes a cyst taken from the vertebral canal of a rabbit by Dr. Emmanuel Rousseau and sent to Leblond, who finds it to be *Cœnurus cerebralis*. De Blainville (1828a) had previously described a cœnurus, which he calls an *Echinococcus*, from the peritoneal cavity of a rabbit. This and subsequent records of the sort have been usually, and probably correctly, taken as cases of *Multiceps serialis*, which was described as a separate species by Gervais (1847a). Gervais and van Beneden (1859b) have examined Leblond's specimen and think it is not *C. cerebralis*. Klencke (1844a) claims to have produced a cœnurus in the rabbit brain by inoculating the brain with bits of rotten cœnurus, but such a claim settles that his record has no right to recognition.

Numan (1850b) states that Engelmeyer in 1850 recorded the presence of a cœnurus in the liver of a cat, and as Numan treats of only one species of cœnurus, the inference is that this was an infection with *Multiceps multiceps*, which, however, would be a highly improbable occurrence. Engelmeyer's article is not available for verification, but Neumann (1893i) has attempted to verify this record and finds that Engelmeyer's case is a quite ordinary record of *Echinococcus* in the liver of a cow. According to Neumann, the error arose from Numan writing "kat" instead of "koe." Neumann criticises Cobbold for translating Numan's "Veelkop" as *Cœnurus* instead of *Polycephalus*. The criticism seems hardly fair to Cobbold, as Numan uses *Cœnurus, Polycephalus*, and "Veelkop" interchangeably to mean one and the same thing, i. e., the gid parasite. And at the point in question, Engelmeyer's case is cited to show that the "Veelkop" is not confined to the brain and spinal cord. Had Numan intended to include *Echinococcus* in his discussion of "Veelkop," he would hardly have referred to one case from the liver as an exception to the rule that it occurs regularly in the nervous system, as the reverse would be true for *Echinococcus*. It is probable that Numan has erred in including Engelmeyer's case in the way he did, and certain that he quoted it wrongly.

Diesing (1850a) and many subsequent writers have listed *Multiceps multiceps* from the camel, the authority, where given at all, being usually De Blainville (1824a). By a coincidence, or by one author misleading the other, Numan (1850b) in the same year assisted in strengthening Diesing's error by also listing the parasite from the camel, basing the statement on De Blainville's case in Aran (1841a). As a matter of fact, Aran says that De Blainville found the parasite in a chamois, and De Blainville himself says it was a chamois. The explanation appears to be that either Diesing or Numan or both of them confused "chamois" and "chameau," or perhaps the printer did. Espejo y del Rosal (1905β) says that Lafosse saw the gid parasite in the camel. Lafosse (1854b) has noted gid in the sheep and (Jacques and Lafosse, 1854b) in the antelope, but never in the camel so far as available records show. At any rate, there is no authority at hand for listing the camel as a host of *Multiceps multiceps*.

It has already been shown (p. 35) that Diesing (1850a) erred in crediting Retzius with listing *Multiceps multiceps* from *Cervus tarandus*, as Retzius (1790a) records it from the chamois, not the reindeer.

Diesing (1850a) also states that what is probably a specimen of *Cœnurus cerebralis* is known "Ex *Ipalacis capensis*." There is no mammal genus from which the genitive "*Ipalacis*" could be derived, and Diesing (1864a) has later given the name as *Spalax capensis*, in this case merely calling the parasite a cœnurus. Von Linstow (1878a) lists the host as *Georhynchus capensis*, and it seems likely that the cœnurus in question was taken from this host, the generic name of which is properly *Georychus*, according to Palmer (1904a). The true *Spalax* does not occur in the locality given. From such a host as this rodent it is altogether unlikely that the parasite was *Multiceps multiceps*.

A writer in the Veterinarian (1855*a*) states that *Cœnurus cerebralis* is found in the brain of the sheep, ox, horse, pig, and man. There is no citation of authorities or cases to back the assertion, and it is evident that the pig is included here through error. Kolster's (1893a) doubtful case has already been discussed.

Fuchs (1859a) lists the gid parasite from the sheep, cow, and horse, specifying the brain and spinal cord in all cases. It seems quite evident that there was nothing but the possibility of its occurrence in the spinal cord of the cow to justify this statement, and as no record of such an occurrence seems to have been made until half a century later, this statement may be rejected.

It has already been pointed out (p. 31) that Von Nathusius's case, as given by Leisering (1862a), who reported it, was one of subcutaneous cœnurus in the sheep. Pagenstecher (1877a), Moniez (1880a), Leuckart (1886d), and Railliet (1893a) have erred in reporting this from the calf or ox. Von Linstow (1878a) has perhaps followed Pagenstecher in listing *C. cerebralis* from under the skin in the cow.

Neumann (1888a) devotes a paragraph to gid in the goose, quoting Hering's (1861*a*) case, and stating that the tumor found on the brain was considered as a dead and atrophied hydatid. As a matter of fact, Hering says that a mass without membranous structure, as is often the case in shriveled bladderworms, was found in the left hemisphere of the cerebrum, but nowhere a hydatid.

Railliet (1893a) states that the cœnurus found by Heincke in the eye of a horse is usually referred to *Cœnurus cerebralis*. Heincke (1882a), according to a secretary's abstract, found a bladderworm in the eye of a foal. Under the microscope the worm showed a hook circlet. There is nothing to indicate that the cestode was a cœnurus, and as the description would fit *Cysticercus cellulosæ*, known as a parasite of the eye and of the horse, it seems more reasonable to consider it as this than to assume, contrary to the evidence of the one circlet of hooks, that we had here a cœnurus in an organ nowhere authentically recorded as a site of *C. cerebralis*, and in a host which is none too certainly listed as a host of cœnurus. Neumann (1888a) considers Heincke's form a cysticercus.

Hassall (1898a), in a list of hosts and parasites, records *Cœnurus cerebralis* from the sanbur, *Cervus unicolor*. As no authority is given, and as no such record is to be found, the case appears to be an error.

Similarly, Vaullegeard's (1901a) record of the same parasite from the eye of the cow and of the antelope is without authority or record of cases and is rejected as improbable and devoid of evidence.

## THE OCCURRENCES OF THE ADULT MULTICEPS MULTICEPS.

So far as the writer is aware, the dog is the only known host of the adult *Multiceps multiceps*. Von Linstow (1878a) lists *Tænia cœnurus* from *Canis lagopus*, but the three authorities referred to by him in this connection, Diesing (1864a and 1864b), Leuckart (1856a), and Krabbe (1865e), do not mention it. Railliet (1893a) states that Möbius found *T. cœnurus* in *Vulpes lagopus*, but no reference is given, and I have been unable to verify this statement. Hence the blue fox must be considered a doubtful host of *Multiceps multiceps*.

Hering (1873a) fed a common red fox, *Canis vulpes*, with larval *Multiceps multiceps* on three occasions and once fed two *Cysticercus tenuicollis*. The fox passed numerous proglottids, but when finally killed post-mortem examination showed only three tapeworms 2 to 3 inches long. According to Hering, these were *T. cœnurus*. They seemed to be when compared with other specimens on naked-eye examination. Further, the fox had been fed for a year and a half on horse meat, and three tapeworms could not have arisen from two cysticerci. However, there were 42 to 48 hooks instead of 28 to 36, and the large hooks measured 0.65 mm. long. Such a hook measurement is four times the average for *Multiceps multiceps*, and if correctly given would make it quite certain that the cestode in question was not *M. multiceps*. The uncertainty is such that *Canis vulpes* must be considered a doubtful host of *M. multiceps* in this case.

Braun (1894a) gives a reference to Fürstenburg (1858a), not available to the writer, and states that Fürstenburg fed *Cœnurus cerebralis* and *Cysticercus tenuicollis* to dogs and foxes and recovered tapeworms 45 to 50 inches long from the dogs and one-fourth to 7 inches long from the foxes. It is uncertain from this statement whether the tapeworms in the foxes included *Tænia cœnurus* or not.

All other statements that the fox is a host of this parasite appear to be mere assumption, without case or authority to support them.

The assertion or assumption that the wolf is a host of *M. multiceps*, made by Küchenmeister (1853e), Von Siebold (1854b), Bourcier (1859a), Gervais and Van Beneden (1859b), Baillet (1866b), and numerous others, is likewise without cases or authority to support it, and the wolf can not even be listed as a doubtful host so far as the records go. In view of the close relationship of wolves to the dog, however, it is very probable that they may serve as hosts of the adult gid parasite.

Equally devoid of basis, so far as actual records are concerned, are the claims made or suggested for the martin by Von Siebold (1854b), Pütz (1882*a*), and Dewitz (1892b), for the coyote by Curtice (1890c), Burch (1893*a*), and Shaw (1901a), and for the polecat by Dewitz (1892b).

Railliet (1893a) states that he has been unable to infect the cat.

The writer has personally examined tapeworms from coyotes and other wolves trapped in Montana, but has not found *M. multiceps.* Doctor McClure, in a letter of December 5, 1906, to Doctor Melvin, says he has examined two coyotes in Montana and found no intestinal parasites.

The following list includes all records found of the occurrence of the adult *Multiceps multiceps* not produced by feeding experiments and many of the cases where it has been produced by experiment. In the case of the latter some effort has been made to avoid duplication, due to translations, later editions, etc. The list does not include those cases where the occurrence of the parasite is merely claimed.

*List of recorded occurrences of the adult Multiceps multiceps in the dog.*

| Locality. | Authority. | Notes and comments. |
|---|---|---|
| Germany | Von Siebold 1852a | By experiment. |
| Do | Küchenmeister 1853e | Do. |
| Do | Haubner 1854b | Do. |
| Do | Von Siebold 1854b | Do. |
| Do | Küchenmeister 1855f | By experiment; first trihedral specimen. |
| (?) | Fürstenburg 1858a | By experiment; according to Braun (1894a). |
| Germany | Hering 1859a | By experiment. |
| France | Baillet 1859b | Do. |
| England | Gamgee 1859a | Do. |
| France | Pouchet and Verrier 1862b | Do. |
| Denmark | Krabbe 1862a | Found in 4 out of 185 dogs. |
| France | Milne-Edwards and Vaillant 1863a. | By experiment. |
| Denmark | Krabbe 1865d | Found in 5 out of 500 dogs. |
| Iceland | do | Found in 18 out of 100 dogs. |
| Faroe Islands | do | Rare. |
| England | Cobbold 1867o | By experiment; never otherwise. |
| Germany | Hering 1873a | By experiment. |
| Italy | Perroncito 1877cc | Do. |
| France | Bertolus and Chauveau 1879a | Found in 1 out of 84 dogs. |
| Germany | Leuckart 1880b | By experiment; a trihedral specimen and 1 with genitalia reversed. |
| Do | Schöne 1886a | Found in 1 out of 100 dogs. |
| Switzerland | Zschokke 1887*a* | Found in 3 out of 177 dogs. |
| France | Neumann 1888a | Not stated. |
| Germany | Deffke 1891a | Found in 1 out of 200 dogs; also by experiment. |
| United States | Curtice 1892g | This is an error; see p. 21. |
| Do | Ward 1896b | Ward (1897b) and Stiles (1898a) think this is *M. serialis.* |
| Germany | Lehner 1897a | Found in 4 dogs. |
| Italy | Calamida 1901c | Not stated. |
| Scotland | Law 1903a | By experiment in 1864 or 1865; date and place furnished me in personal communication of July 2, 1909. |
| Germany | Johne 1904f | By experiment; a trihedral specimen. |
| Australia | Brown 1902*a* | Not available; cited from Sweet 1909*a*. |
| United States | Hall 1909*a* | By experiment. |
| France | Henry 1909*a* | Dog died of intestinal obstruction due to mass of *Multiceps multiceps.* |
| United States | Taylor and Boynton 1910a | One specimen said to have been produced by feeding cœnurus. |
| Do | Hall 1910*β* | This article. |

## ECONOMIC IMPORTANCE OF GID.

In the seventeenth century Scultetus (1672a) notes that gid was common enough then in Germany to be known among the peasantry under the name of "Wirbling." In the eighteenth century Wepfer (1724*a*) says it was a common disease of cattle in Switzerland. Maillet (1836a) says it is more common in southern than in northern

France. Von Siebold (1854b) states that gid is not rare in cattle in south Germany, especially Bavaria, but that it is scarcely known in north Germany, and Zürn (1882*a*) says it causes great loss among sheep in south Germany. Krabbe (1865d) found the adult parasite very common in dogs in Iceland, and the gid disease must have been very common, as he says, for the cystic stage is much more commonly found than the adult. Cobbold (1867o) says the disease is not important in England, but is in Hungary, though later Heatley (1884*a*) says that gid is very common in England. Wernicke (1886a) states that the parasite is viewed with alarm in the Argentine Republic. Möller (1891a) says cœnurus is common in cattle at the Salzburg slaughterhouses, and is not rare in Steiermark, Kärnten, Tyrol, Bukownia, and Dalmatia. Scheben (1910*a*) says that gid is an old trouble in German Southwest Africa, often becoming conspicuous by its damage to sheep breeding, and now and then occurring as an epizootic.

It will be seen from the above that while gid enjoys a wide distribution, there are some districts which appear to favor the disease, and in these places there is a constant and considerable economic loss from the disease. How great that loss is may be judged from a few figures.

Youatt (1834a) says that at least 900,000 sheep die annually of gid in France. (Most authors quote Youatt as saying a million sheep, but I have not found this statement.) Belhomme (1838a) says that in some years gid attacks one-fifth to one-fourth of a flock. Barthelemy (1839*a*) says not less than one-fifth of the lambs suffer from gid in France. Reynal (1852*a*) notes the loss of 50 out of a flock of 110 lambs from this disease, and Clok (1868*a*) notes Kuers's case, where 200 out of 400 died of gid. Reynal (1857a) states that gid attacks from one-tenth to more than one-fourth of the sheep in some places. Von Siebold (1854b) says gid kills more than 10 per cent in some flocks. Clok (1868*a*) says the average yearly loss from gid is 5 to 6 per cent, and that in Germany it may kill 70 per cent of the lambs. Heitzmann (1868a) says that at Rohrdorf 50 to 60 head of cattle die in some years. Dixon (1883*a*) says that before the fencing in of sheep runs began in South Australia it was not unusual for 2 per cent of the hoggets to die of "crankiness," or gid. Neumann (1892a) states that Gasparin put the loss in Germany at 15 per 1,000 the first year, 5 the second, 2 the third, and 1 the fourth. Armatage (1895) says of gid: "The annual losses are about 10 per cent. It always prevails in some districts, particularly in Scotland." Not long ago Penberthy (1906*a*) noted a case in England where 300 out of 400 lambs died of gid inside of four months. Numan (1850b) says that gid is not as common in Holland as in some countries, and claims that Tessier put the loss in France at 5 per cent, and that Kuers in 1840 stated the loss in Germany as no less than this. Diem (1906*a*) points out that with existing values gid in cattle causes an appreciable loss, and notes instances where the values of cattle successfully operated on increased over their slaughter value as giddy animals from 35 and 55 to 485 marks. Vollrath (1905a) states that during the winter and spring of 1904–5 there were one or two cases weekly among cattle at Uttenweiler. Pfab (1910$\alpha$) notes two cases where cattle breeders lost an entire year's increase; in one case 8 animals out of 8, and in another 12 out of 12. He records a total of 58 operations on cattle in the years 1903 to 1909, inclusive, with 34 cures. The figures already given for the United States, and the writer's personal investigation in Montana, show losses of 2 or 3 to 10 per cent among some Montana flocks, and such a loss in a State where sheep are rated by the Bureau of Statistics[a] of the United States Department of Agriculture at $4.20 a head is worth considering. It appears that the loss in Montana amounts to $10,000 in some years, and is at all times a steady drain on the flocks.

It is evident from these figures that gid is really a dangerous and important disease. It has held its own for centuries in civilized Europe. Nearly a century ago, Bosc (1816a) said it was notable for the loss of sheep which it occasioned. Later Eschricht (1840b) speaks of it as a plague. Kuers in 1840, according to Numan (1850b), classed it as one of the three most important diseases of lambs. Eschricht (1841g) says it "often rages * * * as a virulent contagion." Clok (1868$\alpha$) says it may be regarded as producing the greatest comparative loss of all sheep diseases. Van Beneden (1889a) says "The cœnurus of the sheep is a true calamity when it spreads in a country." Dewitz (1892b) says gid is the most important parasitic disease of sheep around Berlin. In Germany the Government was trying to stamp out the disease before the middle of the last century, and Küchenmeister was working under a government grant when he demonstrated the complete life cycle of the parasite in 1853.

The sheep is conspicuous for its comparative freedom from bacterial diseases, a fact especially noticeable at this time, when the cow and other animals are being called to account in the tuberculosis campaign. But the sheep is equally conspicuous for its susceptibility to animal parasites, and of these the gid parasite is one of the most deadly. In this country gid is not as widespread as infection with the stomach worm, *Hæmonchus contortus*, nor is it so general throughout the flocks it attacks as scab. At the same time, the stomach worm at its worst can not claim anything like the approximate 100 per cent lethality of the gid parasite, and the scab parasite is readily eliminated by a rather simple routine treatment, not comparable to the delicate and uncertain surgical treatment necessary to relieve a sheep of the brain parasite. Unlike bacteria, animal parasites show little preference in attacking weak or poor animals, and gid probably selects its victims oftener from strong, vigorous sheep and with less regard to the care given them than even the stomach worm or the scab parasite.

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[a] Crop Reporter, U. S. Department of Agriculture, vol. 12, no. 2, February, 1910.

Neumann (1888a) and many others, previously and since, state that in general giddy animals should be butchered in the first stage of gid, as the meat is still good. In the case of valuable animals, an operation should be undertaken if indicated by favorable symptoms. He also urges that sheep affected with spinal gid should always be killed. His advice is perhaps as good as could be given. In general, the greater value of cattle, as Pütz (1882*α*) has noted, would justify an operation oftener than sheep values would. This is especially true since the wool value of the living sheep is considerably less than the dairy value of the living cow. The figures already quoted from Diem (1906*α*) show the value of successful operations. Operation is, of course, especially indicated in the case of breeding animals. We know of no adequate medicinal treatment for gid, and experiments along this line have so far been unsuccessful. (See Hall, 1909*α* and Moussu, 1910*α*.)

It seems that animals affected with gid seldom get to the larger slaughterhouses, although F. Braun (1906*α*) says he has often found it in meat inspection of cattle. Edelmann (1896a) says *Cœnurus cerebralis* is ordinarily unimportant in meat inspection, but that in Hesse and Sachsen-Meiningen the meat of giddy animals is to be held as depreciated in value or worthless, according to the degree of the disease and the condition of the carcass. Carreau and Rousseau (1909*α*) give directions for detecting giddy sheep in abattoir inspection in France. Lloyd (1909*α*), in an article on meat inspection in England, lists *Cœnurus cerebralis* as one of the most common larval cestode parasites involved in meat inspection, and Clarke (1907*α*), as already noted, says he has met many cases of gid in sheep at the slaughterhouses in England. Moreau (1909*α*), in an article on meat inspection, gives the methods for detection of the gid parasite and lists animals so infected for partial condemnation.

Bourrier, Charpentier, and Lafourcade (1884a) only found the gid parasite once after five and a half years at the Villette abattoir, in spite of a careful examination of the brains of the 18,000 to 20,000 cattle that were slaughtered there monthly. Schöne (1886a) only found it once among 8,962 sheep at Chemnitz.

From a legal standpoint, gid constitutes an impairment of contract in cattle sales in some places in Europe, according to Semmer (1885c), who gives this period as 14 days in Nassau and Thurgau, 15 days in Canton St. Gallen, and 31 days in Canton Schaffhausen. These periods are too short, as Semmer notes. Gerlach (1872a), who gives the same figures, says the period should be three months, but states that such a fixed period can be dispensed with on the ground that only an occasional breeding ram comes up for consideration, and especially because we are in a position from a scientific standpoint to render a correct judgment on any concrete case. Heusinger (1853*a*) states that in the "Ancient Laws and Institutes of Wales" the law governing impairment of contract allows three days for the development of "dera," or vertigo, in sheep, cattle, and horses. I am unable to state whether this covers cases of gid or not.

### ALLEGED CAUSES OF GID.

Before the gid parasite was known as the cause of gid various theories were advanced to account for the disease, and after the parasite was known to be the cause many theories were advanced to account for its presence. Nor did the proposal of new theories cease after Küchenmeister (1853e) had demonstrated the parasite's life history. Below are cited the various theories found by the writer, only one authority being assigned for any given theory.

Stier (1776a) discredits the theories that gid is due to insect larvæ in nose, to inflammation, to stagnation of blood, or to hot days followed by cold nights.

Gericke (1805*a*) considers gid as due to an accumulation of fluid in the head from hypersecretion of glands injured by blows on the animal's head.

Youatt (1834*a*) opposes the theories ascribing the disease to poisonous plants, delay in docking, to hoarfrost, apoplexy, or to weakness of meninges; also Hogg's theory of gid as due to the injection of fluid from the central canal of the spinal cord into brain.

Maillet (1836a) notes the idea that gid in cattle was due to heavy yokes.

Tschudi (1837a) has a footnote, signed Leuckart, which notes that gid occurs in unhorned sheep and that certain formative material should go into the horns the first year, or, failing that, the high blood pressure favors cyst production.

Schellhase (1839*a*) objects to the theory of cachexia and malnutrition as causes of gid and proposes the opposing theory that the heightening of the vegetative life of sheep by suppression of activity in the period of youth causes a superfluity of material which gives rise to worms.

Eschricht (1840b) favors the idea that bad feeding and wet meadows give rise to gid.

Blacklock (1841*a*) adopts a theory, credited by him to Hogg in 1812, that gid is due to the back of the sheep being chilled.

Pluskal (1844*a*) quotes the following theories of spinal gid: That it is due to chilling, metastasis, rheumatic-toxic trouble, too much jumping, excessive stretching of hip ligaments, and feebleness of the ram.

Numan (1850b) notes that gid has been referred to bad food and water, *Colchicum autumnale*, *Allium vineale*, *Ranunculus flammula*, an adder, damp stalls, cutting teeth, and temperature variation.

Reynal (1858a) thinks that gid is due to heredity or the breeding of too young animals.

Gamgee (1859a) cites Naviéres's theory that a fly perforated the sheep's skull and deposited eggs.

Davaine (1860a) mentions the theory of gid as due to precocious obesity.

Dun (1864*α*) puts forth a common mixture of truth and error, rather than a theory, when he says that sheep pick up the eggs or larvæ of tapeworms dropped by dogs, rabbits, or sheep, and that the ova of flukes also cause gid.

Fürstenburg (1865b) condemns Mahnke's theory that gid parasite eggs get into the blood and are destroyed, the dissolved product subsequently uniting with the egg or semen of the host, thus forming a fetus which later becomes the parasite.

Vollrath (1905a) states that in advising farmers to have their cattle operated on for gid he met with marvelous causes for the disease, and this, too, in Germany where the knowledge of the etiology and prophylaxis of the disease has coexisted with the disease for half a century. It is not, therefore, surprising that, according to Doctor Treacy, of this Bureau, in a letter of June 5, 1907, the sheepmen of Montana have been classing the gid trouble as loco, poison weed, water on the brain, grub in the head, etc., "and have not paid any attention to the destruction of the animals that have died."

### NAMES APPLIED TO GID AND GIDDY ANIMALS.

The wide distribution of gid and the peculiarity of its symptoms have led to its receiving a great number of popular names in various languages. In the following lists these names, together with the medical names, have been arranged in chronological order under each country. Where the name is applied to a giddy sheep instead of to the disease it is indicated by an asterisk (*), and where the term applied is an adjective it is indicated by a dagger (†). Spinal gid is indicated thus (§). This list is necessarily incomplete, especially as regards terms used in Asia, from which continent no records of gid are available, although the disease probably occurs there.

The authority cited for a name will often, but not always, be the one found using it first. In every case the question of the propriety of using the word to denote gid, or infection with *Multiceps multiceps*, must be referred to the authority cited.

GERMANY.—Rolfinck 1656a, *Vertigo;* Scultetus 1672a, *Wirbling;* Guetebruck 1766*α*; *Drehnigkeit*, *Dummlichkeit*, *Taubsucht*, *Verrückung der Sinnen;* Batsch 1786a,* *Dreher*,

**Seegler;* Gmelin 1790a, *Drehen, Springen;* Stier 1776a, †*drehende;* Bloch 1782a, *Drehkrankheit*, **Springer*, **Segler;* Frenzel 1794a, †*albern*, *Dämischseyn*, *Drehlinge*, *Drehsucht*, *Dummheit*, †*elbisch*, *Irregehen*, *Kreislauf*, *Läppischseyn*, *Ringlichtwerden*, *Schwindel*, *Seglen*, *Taumeln*, *Traben*, *Verrückung*, *Würflichtseyn;* Rohlwes 1813a, **Dähmeler*, **Ringläufer*, **Traber;* Numan 1850b, *Dummsein*, *Eibischwerden*, *Kopfkrankheit*, *Ringläufen*, *Ringlicht;* Hering 1853α, *Dippelkrankheit*, *Dipplichkeit;* Reynal 1854b, **Wurfler;* Spinola 1858b, **Irrlinger*, **Propheten*, **Schwindler*, **Seitlinge;* Blumenbach 1802a, *Queesenkopfe;* Pluskal 1844α, *Drehe*, §*gebrochenes Kreuz*, §*Gnubberkrankheit*, *Hydrocephalus hydatideus*, §*Hydrops hydatibus medullæ spinalis*, *Hydrops hydatideus ovium*, §*Kreuzdrehe*, §*Kreuzlähme*, §*Tabes dorsalis*, *Traberkrankheit;* Küchenmeister 1855f, *Dreh-Krankheit;* Gurlt 1831a, §*Atrophia medullæ spinalis;* Erdt 1870a, **Reitbahndreher*, **Zeigerdreher;* Gerlach 1872a, *Kollern;* Pütz 1882α, *§*Kreuzdreher*, *§*Kreuzschläger*, **Taumler;* Möller 1891a, *Drehwurmkrankheit;* Friedberger u. Fröhner, 1904α, *Blasenschwindel*, *Drehbewegung*, *Kopfdrehe*, *Kreisbewegung*, *Manegebewegung*, *Narrischsein*, *Quesenkopf*, *Reitbahnbewegung*, *Rollbewegung*, **Schwinder*, *Taumelsucht*, *Tölpischsein*, *Wälzbewegung*, *Zeigerbewegung;* Braun, F. 1906α, †*dämisch;* Diem 1906α, †*würfig;* Worbs 1909α, †*würflig;* Pfab 1910α, *Coenurus-Krankheit.*

FRANCE.—Bloch 1788a, *sauteuse, tourneuse;* Moorcroft 1792a, *tournoiement*, *vertige;* Bosc 1816α, *tournis;* Carrere 1826α, *lourd;* Numan 1850b, **tourneurs;* Reynal 1857a, *avortin*, **cingleur*, *lourderie*, **trotteur*, **voilier;* Cruzel 1869a, *avertin;* Benion 1874a, **portant au vent*, §*paraplégie hydatique;* Neumann 1892a, *étourdissement*, *hydrocéphale*, §*tournis lombaire*, *vertigo;* Armatage 1895, *étourdi*, *éturdi.*

ENGLAND.—Moorcroft 1792a, *gid*, *turn;* Home 1795a, *staggers;* Turton 1806α, *dunt*, *rickets;* Schulling 1821α, *sturdy;* Youatt 1834α, *gig*, *goggles*, *turnsick;* Veterinarian 1855α, *vertigo;* Spooner 1888a, *blob-whirl*, *giddiness*, *sturdy-gig;* Neumann 1892a, §*hydatic paraplegia*, *hydatido-cephalus*, *hydatid on the brain*, §*lumbar gid*, §*medullary gid*, *punt*, *turnside;* Armatage 1893α, *hydrocephalus hydatidæus;* Armatage 1895, *cœnurus cerebralis*, *hydatids;* Penberthy 1897c, *cœnurosis;* Cave 1903α, *pothery.*

LAPLAND.—Hoffberg 1759a, *Ringsjuka.*

IRELAND.—Bellingham 1844a, *staggers.*

SCOTLAND.—M'Call 1857a, *sturdy.*

HOLLAND.—Numan 1850b, **Draaijers*, *Draaiziekte*, **Dravers*, §*Kruislamheid*, §*Schuurziekte*, **Zeilers;* Blumenbach 1802a, *Draaikoppen.*

ITALY.—Fontana 1784a, *folie*, **fols*, *male vertiginoso*, *storno;* Neumann 1892a, *vertigine idatiginosa*, *vertigine per cenuro.*

DENMARK.—Krabbe 1864h, *Dreiesyge.*

CAPE COLONY.—Hellier 1894a, *Mal-Kop;* Buckley 1904α, *Malkopziete*, *Malkop Ziekte;* Hutcheon 1904α, *gid*, *sturdy*, *turnsick;* Gilchrist 1909α, §*lumbar-gid.*

ARGENTINE REPUBLIC.—Armatage 1895, †*moonstruck;* Monfallet 1899α, *locura de las ovejas.*

SOUTH AUSTRALIA.—Dixon 1883α, *crankiness*, *tumsick.*

CHILE.—Monfallet 1899α, *cenurosis*, §*paraplejia hidatica*, *torneo*, *torneo encefalico*, §*torneo lumbar.*

SPAIN.—Monfallet 1899α, *modorra;* Espejo y del Rosal 1905α, *torneo.*

SWITZERLAND.—Retzius 1790a, †*sturmig.*

UNITED STATES.—Livingston 1809α, *dizziness*, *staggers;* Clok 1847α, *water in the head;* Verrill 1870d, *gid*, *sturdy*, *vertigo*, *water-brain;* Tellor 1879a, *hydatid in the brain*, *hydatid of the brain*, *turnsick;* Crutchfield 1880α, *hydatid on the brain;* Killebrew 1880α, *hydatids;* Stewart 1880a, *giddiness*, *turnside;* Powers 1887a, *blind staggers;* Burch 1895α, *turnsids;* Sommer 1896c, *turnstick;* Campbell & Lacroix 1907α, *turn sickness;* letter of Dr. Cary to Dr. Treacy, May 21, 1907, †*locoed.*

The writer finds that in Montana gid is known as loco, lamb loco, bug in the head, and blind staggers, and that giddy sheep are commonly said to be crazy.

To the above list might be added *ʽιερα νοσος*, the Greek for "the sacred disease," epilepsy, by which Hippocrates (1825*a*) designates various forms of vertigo in man and animals, and under which term it is likely that gid in sheep was known. There should also be added the Latin term, "tornatio," used by Acharius (1782) but not assigned to any country.

Unless an author specifies otherwise, it is assumed that a term used by him for gid was in use in the country from which or of which he wrote. This accounts for the terms listed from the United States at a time when it is doubtful whether there was any gid in this country.

As the present writer has not been in a position to check all errors of spelling as such and can not guarantee that they were not local variations, all names are included as found, even where it seems fairly clear that there is an error, as in the case of "turnstick" of Sommer (1896c).

The term "locoed" is included on the strength of Doctor Cary's statement that in his opinion it includes in Montana sheep that are actually suffering from gid, and on the evidence of Dr. E. T. Davison, who reports under date of December 21, 1907, that he has examined several sheep reported as "locoed" and found them all infested with the gid parasite. The writer has found that giddy sheep are very commonly referred to in Montana as locoed, and in one place, where no loco weed or loco disease existed, gid was known as lamb loco.

Such a term as "ringsjuka" is included on the possibility, discussed elsewhere, of the disease in question being gid.

The term "moonstruck," referred to the Argentine Republic by Armatage (1895), is presumably a translation.

### COMMON NAMES OF THE GID PARASITE.

The following list is not complete, but covers the commoner names used in the more important countries, one authority for the name being cited:

Germany.—Blumenbach 1802a, *Die Queese;* Gurlt 1831a, *Gemeinschwanz, Vielkopf;* Küchenmeister 1855f, *Schaafquese;* May 1855a, *Gehirn-Vielkopf*; Leuckart 1863a, *Drehwurm;* Erdt 1870a, *Cœnurusblase;* Zürn 1882*a*, *Gehirnblasenbandwurm, Gehirnblasenwurm, Gehirnquese, Quesenbandwurm.*

France.—D'Arboval 1827a, *cœnure cérébrale;* Von Siebold 1852a, *Ver du tournis;* Neumann 1888a, *cénure cérébrale.*

England.—Moorcroft 1792a, *social hydatid;* Cobbold 1874c, *gid hydatid, many headed hydatid;* Cobbold 1874v, *gid-hydatid tapeworm.*

Holland.—Blumenbach 1802a, *Herszen-Blaas-Worm;* Numan 1850b, *Vielkop-Blaasworm der Hersenen.*

Cape Colony.—Gilchrist 1909*a*, *water-bags.*

United States.—Verrill 1870d, *water brain;* Stiles 1898a, *gid bladder worm.*

A Scotch sheepman in Montana refers to the gid parasite as the "sturdy bag" and states that it is commonly known by this name in Scotland.

## SYNONYMY.

The following table of synonymy is based on over 600 references and is probably very nearly complete. The essential discussion of the correct names of the parasite has already been given under the historical sketch:

### Genus MULTICEPS Goeze 1782a.

1782. *Multiceps* Goeze 1782a.
1782. *Cerebrina* Acharius 1782; erroneously substituted for *Multiceps*.
1782. *Tænia vesicularis* Goeze 1782a, *pro parte*.
1786. *Hydatigena* Goeze 1782 of Batsch 1786a, *pro parte*.
1788. *Vesicaria* Schrank 1788a.
1790. *Hydatula* Abildgaard 1790, *pro parte*.
1798. *Hydatis* Virey 1798a, *pro parte*.
1800. *Polycephalus* Zeder 1800a; *Multiceps* renamed.
1808. *Cœnurus* Rudolphi 1808a; *Multiceps* and *Polycephalus* renamed.
1815. *Polycephops* Rafinesque 1815a; *Polycephalus* renamed.
1818. *Hydatidula* Cloquet 1818a; misspelling for *Hydatula*.
1824. *Cænurus* Bremser 1824a, for *Cœnurus*.
1830. *Cœnureus* Bory de St. Vincent 1830a; misprint for *Cœnurus*.
1830. *Vesicularia* Schrank of Bory de St. Vincent 1830a; Bory de St. Vincent 1830a is author of *Vesicularia;* misspelling for *Vesicaria*.
1831. *Cœnurs* Gurlt 1831a; misprint for *Cœnurus*.
1844. *Canurus* Goodsir 1844g; misprint for *Cœnurus*.
1850. *Tænia* Goeze of Diesing 1850a; in synonymy of *Cœnurus;* Linnaeus 1758a is author of *Tænia*.
1850. *Hydatula* Batsch of Diesing 1850a; in synonymy; Abildgaard 1790 is author of *Hydatula*.
[1870.] *Cœnurias* McClure [1870α]; misprint for *Cœnurus*.
1895. *Cenurus* Armatage 1895; misprint for *Cœnurus*.
1900. *Cystotaenia* R. Leuck. of Braun 1900a; error.
1902. *Vermis* Bloch 1782a of Sherborn 1902a. See discussion of synonymy.
1905. *Cœncerus* Vet. Ed. Amer. Sheep Breeder 1905δ; misprint for *Cœnurus*.
1905. *Cænurus* Cuvier 1825a of Stiles and Stevenson 1905a; Bremser 1824a is author of *Cænurus*. [Schinz, and not Cuvier (1825a), should be held responsible for the use of this form. See discussion of synonymy.]

### Species MULTICEPS MULTICEPS (Leske 1780a) Hall 1910β.

1780. *Tænia multiceps* Leske 1780a.
1780. *Vermis vesicularis socialis* Bloch 1780a.
1782. *Tænia vesicularis cerebrina* Goeze 1782a.
1782. *T. vesicularis, multiceps* Acharius 1782.
1786. *Hydatigena cerebralis* Batsch 1786a.
1787. *Tœnia globuleux* of Chabert 1787a, *pro parte;* misdetermination.
1787. *Ténia globuleux* of Chabert 1787a, *pro parte;* misdetermination.
1788. *Vesicaria socialis* (Bloch 1780a) Schrank 1788a.
1790. *Tænia cerebralis* (Batsch 1786a) Gmelin 1790a.
1790. *Tænia socialis* (Bloch 1780a) Retzius 1790a; probably 1786a.
1790. *Tænia cerebrina* (Goeze 1782a) Retzius 1790a; probably 1786a.
1790. *Tæniae cerebrinae* Retzius 1790a; probably 1786a.
1795. *Tænia hydatigenia* Home 1795a.
1795. *Tænia hydatigena* of Home 1795a; error.
1798. *Hydatis cerebralis* (Batsch 1768a) Virey 1798a.

1800. *Tænia visceralis multiceps* Goeze (1782a) of Zeder 1800a; this combination should be attributed to Zeder 1800a.

1800. *Tænia multiceps* Goeze (1782a) of Zeder 1800a; this combination should be attributed to Leske 1780a.

1800. *Tænia hydatigena* Pallas (1766b) of Zeder 1800a; error.

1800. *Tænia cerebralis* Syst. Nat. Linn. (1790) of Zeder 1800a;=Gmelin 1790a.

1803. *Hydatula socialis* (Bloch 1780a) Schrank 1803a.

1803. *Polycephalus ovinus* Zeder 1803a.

1803. *Polycephalus bovinus* Zeder 1803a.

1804. *Tœnia vesicularis cerebrina multiceps* Goeze (1782a) of Lænnec 1804a; this combination should be attributed to Lænnec 1804a.

1804. *Tœnia cerebralis* Bruguière of Lænnec 1804a; this combination should be attributed to Lænnec 1804a apparently; Bruguière (1792a) uses *Tænia* but does not involve this species; Bruguière (1791a) in the accessible copy has this part in script and hence unreliable; form given is *Ténia cérébral*, unscientific.

1804. *Hydatis cerebralis* Bosc [1802a] of Lænnec 1804a; this combination should be attributed to Virey 1798a.

1804. *Polycephalus cerebralis* (Batsch 1786a) Lænnec 1804a.

1808. *Cœnurus cerebralis* (Batsch 1786a) Rudolphi 1808a.

1810. *Hydatula cerebralis* Batsch (1786a) of Rudolphi 1810a; this combination should be attributed to Rudolphi 1810a.

1810. *Tænia vesicularis* Goeze (1782a) of Rudolphi 1810a; in synonymy; is a generic, not a specific synonym.

1818. *Hydatidula cerebralis* Batsch (1786a) of Cloquet 1818a; this combination should be attributed to Cloquet 1818a.

1818. *Tænia vesicularis cerebrina multiceps* Goëze [1782a] of Cloquet 1818a; this combination should be attributed to Cloquet 1818a.

1825. *C[œnurus] cerebralis* (Batsch 1786a) Bremser 1824a.

[1828.] *Cysticercus tenuicollis* of Buzaringues [1828α] in Reynal 1857a; misdetermination.

1831. *Cœnurs cerebralis* (Batsch 1786a) Gurlt 1831a.

1833. *Cœnurus cerebralis* Lamarck and Rudolphi of Rose 1833a; this combination should be attributed to Rudolphi 1808a.

1834. *Cysticercus tenuicollis* of Youatt 1834α.

1834. *Hydra hydratula* Linnæus of Youatt 1834α.

1837. *Polycephalus cœnurus* Tschudi 1837a.

1837. *Polycephalus cerebralis* Cloquet (1818a) of Tschudi 1837a; this combination should be attributed to Lænnec 1804a.

1844. *Polycephalus cerebralis* V. of Pluskal 1844α; this combination should be attributed to Lænnec 1804a. [V.=Virey?].

1844. *Tænia vesicularis cerebralis* G. of Pluskal 1844α; this combination should be attributed to Pluskal 1844α. [G.=Goeze?].

1844. *Hydatis cerebralis* Bl. of Pluskal 1844α; this combination should be attributed to Virey 1798a. [Bl.=Blumenbach?]

1844. *Hydatis polystomos medullaris* Pluskal 1844α.

1844. "*Tænia cerebralis* (Pennant, Turton)" of Bellingham 1844a; this combination should be attributed to Gmelin 1790a.

1848. *Tœnia vesicularis* Goeze 1782 of E. Blanchard 1848e; this combination should be attributed to Lænnec 1804a, apparently.

1848. *Hydratula cerebralis* (Batsch 1786a) E. Blanchard 1848e.

1850. *Hidatula cerebralis* Batsch (1786a) of Diesing 1850a; this combination should be attributed to Diesing 1850a.

1850. *Cœnurus serialis* Gervais (1847a) of Diesing 1850a et al; misdetermination.

1850. *Hydatis cerebralis* Blumenbach (1802a) of Numan 1850b; this combination should be attributed to Virey 1798a.

1850. *Tænia hydatigena* Fisscher (1788α) of Numan 1850b; this combination should be attributed to Pallas 1766b.
1850. *Tænia vesicularis socialis* Goeze (1782a) of Numan 1850b; this combination should be attributed to Numan 1850b.
1850. *Polycephalus cerebralis, ovinus* Zeder (1803a) of Numan 1850b; this combination should be attributed to Numan 1850b.
1850. *Hydatis polystomos medullaris* Muskal (1844) of Numan 1850b: this combination should be attributed to Pluskal 1844α.
1850. *Polycephalus ovium* Numan 1850b.
1850. *Hydatis facialis* of Dupuy [Date?] in Numan 1850b; Dupuy not available.
1850. *Cœnurus cérébreux* of Dupuy [Date?] in Numan 1850b; Dupuy not available.
1850. *Tænia globuileux* Chabert of Dupuy [Date?] in Numan 1850b; Dupuy not available.
1850. *Hydatis cerebralis* Lemark of Dupuy [Date?] in Numan 1850b; this combination should be attributed to Virey 1798a.
1850. *Polycephalus* (*Cœnurus*) *cerebralis* (Batsch 1786a) Numan 1850b.
1850. *Tænia cerebralis, vesicularis* von Siebold 1850a.
1852. *Tænia cerebralis* Linné of Reynal 1852α; this combination should be attributed to Gmelin 1790a.
1852. *Polycephalus ovium* Zeder (1803a) of Reynal 1852α; this combination should be attributed to Numan 1850b.
1852. *Tænia multiplex* Leuckart 1852b; a corruption of *Tænia multiceps*.
1853. *Tænia cerebralis* Linnæus of Baird 1853a; this combination should be attributed to Gmelin 1790a.
1853. *Hydatis cerebralis* Bosc of Baird 1853a; this combination should be attributed to Virey 1798a.
1853. *Cænurus cerebralis* Rud. of Baird 1853a; this combination should be attributed to Bremser 1824a.
1853. *Tænia cœnurus* (Tschudi 1837a) Küchenmeister 1853e; first naming of strobila form.
1853. *Tæniæ cœnuri* Küchenmeister 1853e; plural of *Tænia cœnurus*.
1854. *Tæniis cœnurus* (Tschudi 1837a) Küchenmeister 1854α; plural of *Tænia cœnurus*.
1854. *Tæniæ cœnurus* (Tschudi 1837a) Küchenmeister 1854α; plural of *Tænia cœnurus*.
1854. *Tenia cœnurus* (Tschudi 1837a) Küchenmeister 1854h; misprint for *Tænia cœnurus*.
1854. *Tænia solium* of von Siebold 1854b; misdetermination.
1854. *Tænia serrata* of von Siebold 1854b; misdetermination.
1854. *T*(*ænia*) *cœnures* van Beneden 1854α.
1855. *Cœnurus serdalis* Gervais (1847a) of Goldberg 1855a; this combination should be attributed to Goldberg 1855a; misdetermination and misprint.
1855. *Hidatula cerebralis* Batsch (1786a) of Goldberg 1855a; this combination should be attributed to Diesing 1850a.
1855. *Cysticercus cerebralis* (Batsch 1786a) Goldberg 1855a; used only in genitive in Latin article.
1856. *Tænia cœnurus* v. Sieb. of Leuckart 1856a; this combination should be attributed to Küchenmeister 1853e.
1856. *T*(*ænia*) *vesicularis cerebralis s. multiceps* Goeze (1782a) of Leuckart 1856a; this combination should be attributed to Leuckart 1856a; see Pluskal 1844.
1857. *Tœnia cerebralis* Linn. of Reynal 1857a; this combination should be attributed to Lænnec 1804a.
1857. *Polycephalus ovinus* Zider of Reynal 1857a; this combination should be attributed to Zeder 1803a.
1858. *Tnia cœnurus* (Tschudi 1837a) Baillet 1858c; misspelling.
1859. *Tænia marginata* Götze of Fuchs 1859a; error.
1859. *Tæna serrata* R. of Hering 1859a; this combination should be attributed to Hering 1859a; misdetermination, misprint.

1859. *Tænia e cœnuro* Aut. of Hering 1859a.
1859. *Tœnia cœnurus* (Tschudi 1837a) Keller 1859a; misspelling.
1860. "*Echinococci*" of Crisp 1860a; error.
1861. *T(ænia)* *cœnura* Kœberlé 1861a; misprint.
1861. *T(ænia) cœnara* Kœberlé 1861a; misprint.
1861. *C(ystjcercus) cœnurus* (Tschudi 1837a) Kœberlé 1861a.
1861. *Tenia canurus* van Beneden 1861a.
1863. *Polycephalus cerebralis* Numan of Diesing 1863b; this combination should be attributed to Lænnec 1804a.
1863. *Cœnurus cerebralis ? leporis cuniculi* Baillet of Diesing 1863b; in synonymy of *Tænia cœnurus*; not at present available, cited from Diesing 1864a, identical; this combination should be attributed to Diesing 1863b.
1863. *Tænia (Cystotænia) cœnurus* Leuckart 1863 of Diesing 1863b; this combination should be attributed to Diesing 1863b.
1863. *Tænia serrata* Siebold of Diesing 1863b; this combination should be attributed to Goeze 1782a; error.
1863. *Tænia cœnuri cuniculi* Baillet of Diesing 1863b; this combination should be attributed to Diesing 1863b; error.
1863. *Ténia-serrata* of Letort 1863a.
1863. *Tænia multiplex* Götze of Leuckart 1863a; this combination should be attributed to Leuckart 1852b.
1863. *Hydatis polycephalus cerebralis* (Batsch 1786a) Randall 1863a.
1866. *Cœnurus cerebralis* Küch. of Baillet 1866a; this combination should be attributed to Rudolphi 1808a.
1868. *Cysticercus cænurus* Desmonceaux 1868a.
[1870.] *Cœnurias cerebralis* (Batsch 1786a) McClure [1870α]; misspelling.
[1870.] *Tœnia solium* of McClure [1870α]; error.
[1870.] "*Echinococcus, polymorphus* or *vetrinorium*" of McClure [1870α]; error.
1874. *Tænia ovilla* of Bénion 1874a.
1877. *Tænia cœnurus* v. Sieb. of Pagenstecher 1877a; this combination should be attributed to Küchenmeister 1853e.
1878. *Cœnurus cerebalis* von Linstow 1878a; misprint.
1879. *Tænia cenurus* Tellor 1879a; misprint.
1879. *Tænia cænurus* (Desmonceaux 1868a) Bertolus et Chauveau 1879a.
1879. *Tœnia cænurus* (Desmonceaux 1868a) Bertolus et Chauveau 1879a.
1880. *Tænia multiplex* Göze of Leuckart 1880b; this combination should be attributed to Leuckart 1852b.
1880. *T(ænia) visceralis; cerebrina* Küchenmeister 1880a.
1880. *Verm. vesical. socialis* (Bloch 1780a) Küchenmeister 1880a.
1880. *Polycephalus granulosus* Zeder of Küchenmeister 1880a.
1880. *Cœnurus cerebralis* auct. of Moniez 1880a; this combination should be attributed to Rudolphi 1808a.
1882. *Tænia cænurus* Sieb. of de Lanessan 1882a; this combination should be attributed to Bertolus et Chauveau 1879a.
1882. *Cænurus serialis* (Gervais 1847a) Perroncito 1882a; misspelling; misdetermination.
1882. *Cænurus særialis* Gerv. of Perroncito 1882a; this combination should be attributed to Perroncito 1882a; misspelling; misdetermination.
1882. *Tænia cœnurus canis* Zürn 1882α.
1882. *Cœnurus cerebralis ovis* Zürn 1882α.
1882. *Cœnurus serialis* Baillet of Zürn 1882α; this combination should be attributed to Gervais 1847a; misdetermination.
1882. *Cysticercus e Tænia cœnur.* Zürn 1882α.
1885. *Tænia cœnur. cerebralis* (Batsch 1786a) Reinitz 1885a.
1886. *T[ænia] cœnure* Brocchi 1886a.

1887. *Tenia cœunuruz* Besnard 1887a; misspelling. [Besnard 1887a is a review of Besnard 1886a, not available to me.]
1893. *T(ænia) cœnusus* Burch 1893α; misprint.
1894. *Polycephalus ovis* Braun 1894a.
1895. *Cenurus cerebralis* (Batsch 1786a) Armatage 1895.
1898. *Vermis vesicularis socialis* Bloch 1782 of Stiles 1898a; this combination should be attributed to Bloch 1780a.
1898. *C(enuro) cerebralis* (Batsch 1786a) Bosso 1898α.
1901. *C[ystotænia] cœnurus* (Tschudi 1837a) Benham 1901a.
1901. *Tenia cænurus* (Desmonceaux 1868a) Perroncito 1901a.
1901. *Tænia cœnurus* Van Ben. of Vaullegeard 1901a; this combination should be attributed to (Tschudi 1837a) Küchenmeister 1853e.
1902. *Cœnurus cerebralis bovis* Mayr 1902a.
1903. *T(ænia) cærunus* Buysson 1903α; misprint.
1903. *Cœnurus cerebrales* Law 1903a; misprint.
1904. "*T.* [(*Cystotænia*)] *cœnurus* Küchenmeister of Leuckart 1853" of Stevenson 1904b; see Diesing 1863b.
1905. *Tænia multiceps* (Zeder 1800) Rudolphi 1802 of Stiles and Stevenson 1905a; this combination should be attributed to Leske 1780a.
1905. *Hydatis cerebralis* (Batsch 1786a) Blumenbach 1816a of Stiles and Stevenson 1905a; this combination should be attributed to Virey 1798a.
1905. *Cœnurus cerebralis* (Batsch 1786a) Cuvier 1825a of Stiles and Stevenson 1905a; this combination should be attributed to Rudolphi 1808a; form intended, apparently, *Cænurus cerebralis.*
1905. "*T.* [(*Cystotænia*)] *cœnurus* Küchenmeister of Leuckart 1863" of Stiles and Stevenson 1905a; see Diesing 1863b.
1905. *Polycephalus cerebralis* (Batsch 1786a) Lænnec 1812 of Stiles and Stevenson 1905a; this combination should be attributed to Lænnec 1804a.
1905. "*Hidatula cerebralis* (Batsch) of Goldberg 1855a" of Stiles and Stevenson 1905a; see Diesing 1850a.
1905. *Multiceps socialis* (Batsch 1786a) Stiles and Stevenson 1905a.
1905. *Hydatigena socialis* Batsch 1786a of Stiles and Stevenson 1905a; this combination should be attributed to Stiles and Stevenson 1905a.
1905. *Cysticercus cœnurus* (Küchenmeister 1853) Koeberlé 1861a of Stiles and Stevenson 1905a; this combination should be attributed to (Tschudi 1837a) Koeberlé 1861a.
1905. *Tænia cœnurus* (Küchenmeister 1853) v. Beneden 1861a of Stiles and Stevenson 1905a; this combination should be attributed to (Tschudi 1837a) Küchenmeister 1853e.
1905. *Cœncerus cerebratis* Vet. Ed. Amer. Sheep Breeder 1905δ; misprint.
1908. *Tenia cenurus* (Tellor 1879a) Germain 1908α.
1908. *Tænia cerebrales* (Law 1903a) Luckey 1908α; misprint.
1909. *T(ænia) cœnurns* Braun 1909; in Braun u. Lühe 1909α; misprint.
1909. *Cœnurus eerebralis* Braun 1909; in Braun u. Lühe 1909α; misprint.
1909. *Tænis cœnurus* (Tschudi 1837a) Hall 1909α; misprint.
1910. *Tænia cœnuris* Kildee 1910α; misprint.

Acharius (1782) uses the form *T. vesicularis multiceps; Cerebrina.* As *Cerebrina* is substituted for *Multiceps*, used in generic sense in Goeze's (1782a) *Tænia vesicularis, cerebrina; Multiceps*, it has been credited as an erroneous generic synonym.

In crediting the genus *Hydatis* to Virey (1798a), the prior use of the same word by Goeze (1782a) has been taken into consideration;

Goeze, however, does not use it generically, but merely as a common noun, hence this word as used by him has no standing in nomenclature. Stiles and Stevenson (1905a) in passing judgment on "*Hydatis* Goeze 1782a," given by them in the synonymy of *Echinococcus*, state in comment, "Very doubtful whether this is used in generic sense."

Goeze uses the word *Hydatis* to refer to water bladders, apparently considered as nonparasitic, found in animal bodies; in fact, uses it in just the sense in which Hippocrates and other Greeks used the same word "*ὑδατις*," meaning the same thing, a water bladder. Goeze denotes by it substantially the same things that are included in the genus *Acephalocystis* Lænnec (1804a), with the essential difference that the objects in question are not regarded as parasites, and hence, in this case, not as animals. Therefore the word has no more standing in nomenclature than the word "Wasserblase," which is regularly used as its equivalent. Larval cestodes are constantly referred to by Goeze in this work as "Eingeweidebandwurm" or "Blasenbandwurm," and the generic and specific names are summed up in a section which does not include the word *Hydatis* and which precedes any use of this word. The word *Hydatis* is used to denote an object which is compared to or contrasted with a "Blasenbandwurm." Thus he states that *Tænia hydatigena* is very similar to the "Wasserblasen (Hydatis)." Again, he states that the true water bladders—"die eigentlichen Wasserblasen (Hydatides)"—are very different from the bladders in which bladderworms, "Blasenwürmer," live. In his final use of the word he states that he found a bladder, "Blase," in the liver of a pig. He adds that it was no "Wasserblase oder Hydatis," for on opening it he found the worm in it. If *Hydatis* is a genus at all in Goeze's work, it is a genus of larval cestodes or "Blasenwürmer." The references show that it is specifically differentiated from such forms.

Sherborn (1902a) has also referred the genus *Hydatis* to Virey (1798a). Virey calls it a genus and appends the generic characters.

Sherborn (1902a) has listed *Vermis* as a genus of Bloch (1782a). Bloch's genus is *Vermis vesicularis*, with the three species *socialis*, *eremita*, and *teniæformis*. It therefore appears that the genus *Vermis* of Sherborn (1902a) must be regarded as an additional synonym of *Multiceps*.

The writer attributes the form *Tænia* (*Cystotænia*) *cœnurus* to Diesing (1863b), and *C*(*ystotænia*) *cœnurus* to Benham (1901a) for the reason that so far as can be determined, the forms in question are first used by these writers. Leuckart's (1863a) responsibility for the form *Cystotænia* ends with that form. The fact that he proposed this as a subgenus may be taken to imply its application to the forms falling within the definition of this subgenus, but such application involves a certain judgment of cases which we can not postulate as perfectly clear, and it is too much to suppose that Leuckart should be held responsible for any or all forms involving the name *Cystotænia* when it may be that a given form is based on a judgment or an error for which Leuckart would not care to be responsible. When a writer proposes a new genus or subgenus he has the option of also proposing the new combinations involved and assuming responsibility for them, or of leaving such an act and its responsibility to some one else and only assuming the responsibility for the genus or subgenus proposed.

The reason for crediting the use of *Cœnurus* to Schinz (see Cuvier 1825a) and not to Cuvier (1825a) is the same as the reason why *Tænia cerebralis* is credited to Gmelin (1790a) and not to Linnæus. Schinz has used here forms not used in the French edition of 1817 of which this is an emended translation, and it is obviously unfair to hold Cuvier responsible for forms not used in the original article.

## MULTICEPS SERIALIS.

### HISTORICAL SKETCH.

It has already been pointed out (p. 38) that Lænnec (1804a) stated that the gid parasite occurs in the sheep, the cow, and perhaps in the rabbit, and that this reference to the gid parasite in the rabbit appears to have been based on hunters' reports of gid in rabbits. It has also been stated that Cloquet (1818a) included the rabbit as a host of the gid parasite without reservation, but his statement appears to be based on Lænnec's (1804a or 1812a) article and is therefore of no value. Neither of these articles, then, can be considered as erroneous records of *Multiceps serialis* under the name of *Cœnurus cerebralis*.

The first record of *M. serialis* is that of de Blainville (1828a) who described a cyst, which he calls an *Echinococcus*, from the peritoneal cavity of a wild rabbit. He noted the serial arrangement of the heads, which afterwards was made the reason for the specific name, and thought that it might be a new species, or might be *E. veterinorum*. Despite de Blainville's decision that the form was probably *Echinococcus*, his article shows evidence of a misconception of that genus and of errors of observation, and it is quite certain that the parasite was *Multiceps serialis*. It is so considered by Gervais and van Beneden (1859b) and by Railliet (1882a).

*M. serialis* is a widely distributed form, long considered as *M. multiceps* or confused with that form by some writers. It is of less economic importance than *M. multiceps* owing to its occurring in the connective tissue and musculature of rodents instead of in the central nervous system of wild and domestic ungulates, as is the case with *M. multiceps*.

Five years after de Blainville's (1828a) record, Rose (1833a) noted *M. serialis* in rabbits in England and stated that warreners, before sending affected rabbits to market, punctured the tumor caused by the parasite and squeezed out the fluid. Rose described the production of daughter vesicles by budding, but did not find this or any other feature a sufficient structural difference between this parasite and the gid parasite to warrant making a new species. Later, Rose (1844a) described a new case and discussed the cyst surrounding the parasite and the external budding of the latter.

Leblond (1837a) notes that Dr. Emmanuel Rosseau sent him a cyst a little larger than a nut from between the spinal membranes of a rabbit. Leblond identified the parasite as *Cœnurus cerebralis.*

Leblond's specimen was later examined by Gervais (1847a), who makes a new species of it on the basis of the serial arrangement of the heads and the long folded neck. From the first feature he named it *Cœnurus serialis.* Railliet (1889o) refers this name to an article in the Dictionnaire Universel d'Histoire Naturelle (v. 6,p. 729), under date of 1845. This reference is correct for the date 1861, but there appears to be no such reference for 1845, and it is possible that Railliet has erred in giving this date. Gervais calls his form *Cœnurus serialis* n. sp. in 1847, and it seems likely that this is the date of its first description. Stiles and Stevenson (1905a) appear to have followed Railliet in citing "*Cœnurus serialis* Gervais, 1847a, 98; probably 1845, 729, not accessible to us."

Baillet (1858b) produced the adult tapeworm in the dog by feeding the cœnurus from the rabbit, and described it but did not name it, as both the adult and larva seemed very similar to the corresponding forms of the gid parasite. Feeding experiments in which the attempt was made to infect rabbits and sheep with the proglottids of the adult tapeworm were not well carried out and showed nothing.

Later, Baillet (1863a) produced the tapeworm again and named it *Tænia serialis.* Proglottids with developed eggs were fed to rabbits and produced the cœnurus. Ten attempts to infect rabbits with the eggs of the adult *Multiceps multiceps* and five attempts to infect sheep with the eggs of the adult *Multiceps serialis* failed. Baillet gives a very full description of the adult and larval *M. serialis.*

Perroncito has stood out against the validity of this species. He records (Perroncito, 1875a) a cœnurus from a rabbit, and although he finds a yellow color present which he does not find in the cerebral cœnuri of ruminants, he nevertheless considers that all cœnuri arise from *Tænia cœnurus.* Later, Perroncito (1882a) finds the only difference between the rabbit and sheep cœnuri to be in the formation of daughter vesicles in the former, and still considers them the same species. At a quite recent date (Perroncito, 1901a), this opinion is still adhered to. The same opinion has been expressed even more recently by Friedberger und Fröhner (1904$\alpha$).

A careful study of *M. serialis* was made by Reinitz (1885a), who concluded that Lindemann's (1867a) *Cœnurus lowzowi* was *M. serialis*, but that Boettcher's (1862a) *Cysticercus botryoides*, Pagenstecher's (1877a) cœnurus from *Myopotamus coypus*, and Mégnin's (1880d) *Cœnurus polytuberculosus* from *Dipus sagitta* were not.

Kunsemüller (1903a) has made an excellent comparative study of *M. serialis* and *M. cerebralis*.

Brandegee (1890a) records the parasite from the United States and notes that two species of rabbits were never found infected, though hundreds were examined, only the California hare being infected. She surmises that the wolf is a probable host, and the coyote, lynx, and fox possible hosts of the adult cestode.

## THE HOSTS AND OCCURRENCES OF THE LARVAL MULTICEPS SERIALIS.

Inasmuch as the list of doubtful and erroneous records is very short, such cases are included here with the certain and probable cases and their standing given in the discussion. No attempt is made to distinguish between hares and rabbits in the following list. They are all listed as rabbits.

*List of occurrences claimed for the larval Multiceps serialis.*

| Host. | Locality. | Authority. | Notes and comments. |
|---|---|---|---|
| Rabbit | France | De Blainville 1828a | One case. |
| Rabbit (*Lepus cuniculus*). | England | Rose 1833a | A number of cases implied. |
| Rabbit | France | Leblond 1837a | One case from vertebral canal. |
| Do | England | Rose 1844a | One new case. |
| Do | France | Gervais 1847a | Leblond's specimen described as a new species. |
| Do | do | Baillet 1858b | Produced adult worm in dogs. |
| Do | do | Baillet 1863a | Produced adult and larval worm by feeding; failed to infect sheep with eggs of *M. serialis* or rabbits with eggs of *M. multiceps*. |
| Squirrel | England | Cobbold 1864b | Host from America. |
| Rabbit | United States (?) | Valentin (date?) | Not seen; cited from Leuckart (1865a.) |
| Rabbit (*L. timidus*). | Russia | Lindemann 1867a | Described as *Cœnurus lowzowi;* not available; considered by subsequent writers as *M. serialis*. |
| Rabbit | France | Troisier 1874a | One case. |
| Do | do | Arloing [1875?] | Per Railliet 1882a; Arloing in Brunet 1875a does not claim to have found it. |
| Do | Italy | Perroncito 1875a | One case. |
| Do | England | Cobbold 1876b | Rose's specimens in Guy's Museum and some in Oxford collection. |
| Do | Scotland | do | One specimen in Cobbold's collection. |
| Do | France | Davaine 1877a | One case recorded and others claimed; specimen exhibited first shown by Bailly in 1861; claims that Prince has found this form in France. |
| Coypu (*Myopotamus coypus*). | Germany | Pagenstecher 1877a | From Berlin Zoological Gardens. |
| Rabbit | Italy | Perroncito 1878h | Listed from title; article not available. |
| Squirrel (*Sciurus vulpinus?*). | England | Cobbold 1879b | Same case as Cobbold (1864b). |
| Rabbit | England (?) | do | Note that Alston has found cœnurus in rabbit. |
| Klippdas (*Hyrax capensis*). | Not given | do | Error, due to confusing records of Gervais (1847a) and Pagenstecher (1877a). |
| Gray squirrel | United States | Stewart 1880a | Probably a reference to Cobbold's (1864b) case. |
| Rabbit | do | do | Claimed to occur; no cases or authorities cited. |

*List of occurrences claimed for the larval Multiceps serialis*—Continued.

| Host. | Locality. | Authority. | Notes and comments. |
|---|---|---|---|
| Squirrel (*Sciurus vulgaris*). | France | Cagny 1882a | One case. |
| Rabbit | do | do | One specimen exhibited by Railliet in discussion. |
| Do | Italy | Perroncito 1882a | Number of cases not given. |
| Do | Germany (?) | Braun 1885c | One specimen. |
| Do | Russia (?) | Reinitz 1885a | Three specimens studied. |
| Do | France | Railliet 1889n | One case. |
| Do | do | Railliet 1889o | Second spinal case; simultaneous connective tissue infection with 9 other cœnuri. |
| Rabbit | New Zealand | Thomas 1889a | Not available; cited from Braun (1894a). |
| Rabbit (*Lepus californicus*). | United States | Brandegee 1890a | Many cases in California; paper read in 1882. |
| Rabbit | France | Villain and Bascou 1890*a*. | Not available; cited from Morot (1900c); one case. |
| Do | do | Leclerc 1890*a* | Not available; cited from Morot (1900c); several cases. |
| Do | do | Railliet 1891i | One case; parasite lived over 2 years. |
| Rabbit (*L. variabilis*). | Russia | Voigt 1891a | One case. |
| Rabbit (*L. californicus* and *L. texianus*). | United States | Curtice 1892g | Number of cases not given; in Texas and California. |
| Rabbit | England | Robinson 1892a | One case; scolices with 6 suckers. |
| Do | Italy | Condorelli-Maugeri 1893a. | One case; under pericardium. |
| Do | Japan | Janson 1893c | One case; listed as *Cœnurus cerebralis*. |
| Do | France | Mégnin 1895 | Not available; cited from Morot (1900c); several cases. |
| Do | do | Lucet 1897b | One case; 28 cœnuri. |
| Do | do | Vignon 1897a | Not available; cited from Morot (1900c), who considers Vignon's *Echinococcus* a cœnurus. |
| Do | United States | Ward 1897 b | Common in Nebraska. |
| Horse | do | Stiles 1898a | Doubtful case, already noted under *M. multiceps*. |
| Rabbit | Italy | Bosso 1898*a* | One case. |
| Rabbit (*L. callotis*). | United States | Hassall 1898a | Specimens seen by Stiles or Hassall. |
| Rabbit (*L. cuniculus*). | Not North America. | do | Do. |
| Rabbit | France | Railliet 1899b | Specimen with many abnormal scolices. |
| Do | do | Morot 1900c | Four cases with 4, 11, 20, and 70 cœnuri, in each host; 1 in eye orbit. |
| Do | do | Gallier 1900a | One case. |
| Do | Siberia | Von Linstow 1901e | Four specimens in St. Petersburg museum. |
| Do | Italy | Parona 1902f | Two cases. |
| Do | France | Buysson 1903*a* | One case. |
| Rabbit (*L. cuniculus domesticus*). | Germany(?) | Kunsemüller 1903a | One case; specimen collected in 1874. |
| Rabbit | England | Byerly 1905*a* | One case. |
| Do | do | Jowett 1905*β* | Has found it. |
| Do | United States | Ransom 1905d | Specimen No. 1823 figured. |
| Do | Scotland | Taylor 1905a | Two cases. |
| Goat | India | Gaiger 1907*a* | Do. |
| Do | do | Holterbach 1907*a* | Note of Gaiger's (1907*a*) case. |
| Rabbit | Not given | do | Sic. |
| Cat | do | do | Sic; error. |
| Squirrel | do | do | Sic. |
| Sheep | do | do | Sic; error. |
| Horse | do | do | Sic. |
| Rabbit (*L. californicus*). | United States | S. E. Piper, in litt. Apr. 14, 1908. | In Nevada; several cœnuri fed to dog. |
| Rabbit | do | Curtice, in litt. July 26, 1909. | In Colorado and California in 1887 and 1888. |
| Goat | India | Dey 1909*a* | One case: cysts in brain and connective tissue. |
| Rabbit | Switzerland | Galli-Valerio 1909*a* | One case; 1 specimen showed 6 suckers. |
| Do | England | Gray 1909*a* | Has seen it in eye orbit. |
| Do | France | Henry 1909*a* | Cœnurus attained volume of 800 c. c. |
| Do | New South Wales. | Johnston 1909*a* | Listed. |
| Rabbit (*Oryctolagus cuniculus*). | Victoria(?) | Sweet 1909*a* | One case. |
| Rabbit | United States | Dr. Young in litt. Oct. 9, 1909. | In North Dakota. |
| "Sage rabbit" | do | Thos. Large, in litt. Jan. 6, 1910. | In Idaho. |
| Rabbit | United States | Hall 1910*β* | This article. |

The following specimens of *M. serialis* from the United States are available to the writer.

| Host. | Locality. | Collector and date. | Collection. |
|---|---|---|---|
| *Lepus californicus* | California | Curtice 1890 | B. A. I. coll. No. 1823. |
| *Lepus sp* | (?) | (?) 1894 | B. A. I. coll. No. 1826. |
| *Lepus callotis* | New Mexico | Townsend 1896 | B. A. I. coll. No. 2798. |
| *Lepus sp.* | (?) | (?) | B. A. I. coll. No. 2608. |
| Do | Michigan | Hayward 1904 | B. A. I. coll. No. 3948. |
| *Lepus californicus* | California | Adams 1905 | B. A. I. coll. No. 3889. |
| *Lepus c. walla-walla* | Oregon | Piper 1907 | B. A. I. coll. No. 14728. |
| Do | do | do | B. A. I. coll. No. 14729. |
| Do | do | do | B. A. I. coll. No. 14730. |
| *Lepus sp* | Nevada | Hall 1910 | B. A. I. coll. No. 15599. |
| Do | Nebraska | Young 1905 | Coll. Hall. |

The first of the above lists shows that *Multiceps serialis* has been claimed to occur in the hare, rabbit, squirrel, coypu, goat, horse, klippdachs, sheep, and cat. Records of its occurrence in the hare and rabbit are undoubtedly correct, the records from the squirrel are probably correct, those from the coypu and goat may be correct, the record from the horse is doubtful, as heretofore indicated, and those from the hyrax, sheep, and cat are errors.

Cobbold (1864b) found a cœnurus in an American squirrel, *Sciurus vulpinus*?, which he thought might be the same species that Rose (1833a) found in "bladdery rabbits." This conclusion appears to be substantiated by the subsequent finding by Cagny (1882a) of a cœnurus in a squirrel, *Sciurus vulgaris*, which had been caught young and kept three years. Cagny's specimen was examined by Mégnin and Railliet who pronounced it *Cœnurus serialis*. Kunsemüller (1903a) thinks Cobbold's cœnurus may be *C. serialis*. If these authorities are right in their identification of this parasite, its rarity in this host is to be expected, as the squirrel's food is of such a nature, consisting as it does largely of nuts, that fecal contamination by carnivorous hosts of the adult worm would only occur very rarely.

Stewart (1880a) writing from the United States, says: "The presence of this parasite [*Cœnurus cerebralis*] has been discovered in the liver of our gray squirrel and in rabbits, as well as in numerous sheep in this country." It is probable that the allusion to the parasite from the squirrel is a reference to Cobbold's (1864b) case of a cœnurus in an American squirrel. The reference to cœnurus forms having been found in American rabbits seems likely enough from our knowledge of the common occurrence of *M. serialis* in this country, but Stewart's record is uncertain, as he does not claim to have seen such a parasite, nor does he cite anyone who has.

Lindemann (1867a), according to a review by Rudnew (Lindemann 1868b), described a *Cœnurus lowzowi* from the rabbit in Russia, in an article not available to the writer. This has since been very generally regarded as *C. serialis* by helminthological writers, among whom are Pagenstecher (1877a), Moniez (1880a), Braun (1897a), and Kunsemüller (1903a). The review of 1868 says there were no hooks in this form but other writers say the hooks were all the same size. Pagenstecher (1877a) says they were all the same size and finds the same thing in one scolex of his cœnurus from *Myopotamus coypus*. Moniez (1880a) says the same and considers it either an error in observation or a teratological fact. Railliet (1899b) has found a great number of abnormalities in *Multiceps serialis*. In view of this fact and the unanimity of opinion concerning this form it has been accepted here as *M. serialis*.

Pagenstecher (1877a) describes a cœnurus which he identifies as *Cœnurus serialis* from the neck of *Myopotamus coypus*. Reinitz (1885a) and Braun (1897a) think this form from the coypu is not *M. serialis*. Moniez (1880a) and Railliet (1882a) accept it as *M. serialis*, and Kunsemüller (1903a) states that he agrees with Moniez and Railliet and disagrees with Reinitz and Braun. In view of this disagreement, the form is provisionally accepted as *M. serialis*, as originally described.

Cobbold (1879b) has the following:

> The klipdas or dasse (*Hyrax capensis*) is infested by a tapeworm. * * * Under the name of *Cœnurus serialis* a larval cestode has been described by Gervais, the same parasite being called *Arhynchotænia critica* by Pagenstecher ("Zur Naturgeschichte der Cestoden." * * *).

In the index this appears as "*Cœnurus serialis* of the hyrax."

Cobbold is in error in stating that Gervais described *Cœnurus serialis* from the hyrax. As has been pointed out, his specimen was from the rabbit. Moniez (1880a) notes that Cobbold has confused Pagenstecher's (1877a) statements, and Railliet (1882a) has stated that Cobbold has listed *C. serialis* from *Hyrax capensis* as a result of some confusion.

Gaiger's (1907α) and Dey's (1909α) records of *M. serialis* from the goat in India are provisionally accepted; a more extended discussion of these and other forms will be given in a subsequent paper dealing in part with the morphology of *Multiceps spp.* Holterbach's review of Gaiger's (1907β) paper contains a number of errors in the list of hosts of *M. serialis*.

The list of occurrences shows that the parasite has been reported from France, England, Scotland, Italy, Russia, Siberia, Switzerland, Australia, New Zealand, Japan, India, and the United States. Whether the parasite occurs in Germany is doubtful. Pagenstecher's (1877a) cœnurus was collected from a coypu in the Berlin Zoological Garden, and hence the origin of the parasite is in doubt. Reinitz (1885a) does not state where his three specimens were collected, but says that one was the specimen discussed by Braun (1883c) before the Dorpat Naturforscher Gesellschaft and the other two were from Prof. Semmer. Braun (1883c) says of the specimen mentioned that he owes it to "dem Herrn. stud. med. Hasenjäger," from which it would appear that it was collected in Germany. Later, however, Braun (1897a) lists the parasite from Russia on the authority of Reinitz (1885a) and Voigt (1891a), but in giving the distribution of this form he does not mention Germany. Still later, Braun (Braun u. Lühe, 1909*a*), writing of the tapeworms of the domestic animals, refers to "Die in Deutschland noch nicht wohl aber in Frankreich beobachtete und sicher auch in Russland bei Hunden workommenden *T. serialis* Baill." On the face of it, this statement can hardly be taken to mean more than that the adult *T. serialis* has not yet been observed in dogs in Germany, and Braun's English translator (Braun u. Lühe, 1910*a*) does not seem to have sufficient reason, especially as regards Germany for the statement that "*T. serialis* Baill. * * * occurs in dogs in France, and probably also in Russia, though not in Germany." Kunsemuller (1903a) does not give any locality for his specimens.

The common occurrence of *M. serialis* in rabbits in the western part of the United States makes it unlikely that this parasite was imported into this country from the Old World, while its wide distribution abroad and its apparent absence from the eastern part of this country makes it equally unlikely that it was carried abroad from this country. Its presence in Oregon and in Siberia points to the strong possibility of its having spread by way of far northern routes over its present wide range of distribution.

*M. serialis* has been recorded from the vertebral canal by Leblond (1837a) and Railliet (1889o), in the latter case with an accompanying infection of the more usual connective-tissue locations. It has been recorded from the pericardium once by Condorelli-Maugeri (1893a), from the eyelid by Byerly (1905*a*), and from the orbit of the eye by Gray (1909*a*), and by Mr. S. E. Piper of the Bureau of Biological Survey of the Department of Agriculture in data furnished the writer.

The number of parasites varies from one, a very common record. to 70 in one case of Morot (1900c), and in size the cyst may attain a volume of 800 c. c., as in the case of Henry (1909*a*). The parasite may live over two years according to Railliet (1891i). Abnormal specimens have been noted by Pagenstecher (1877a) from the coypu, by Robinson (1892a), Railliet (1899b), and Galli-Valerio (1909*a*), from the rabbit, and Lindemann's (1867a) specimen was probably such.

Successful operations for the parasite have been noted by Railliet (1889n) and Byerly (1905*a*).

Mr. Piper, who has furnished the Bureau collection with specimens as noted above, has also furnished us data stating that the parasite was found in 7 out of 12 rabbits examined in Oregon, a pint of cysts being taken from the peritoneal cavity of one. Mr. Piper also collected *M. serialis* in Nevada in 1908, as noted in the table, and fed a number to a dog. The dog was shipped to this laboratory, but did not develop the adult parasite, probably owing to diarrhea resulting from intestinal irritation by too many scolices. The writer has since collected *M. serialis* in Nevada, and developed the adult worm by feeding scolices to a dog. Mr. Graybill, of this laboratory, has also collected *M. serialis* in Texas and fed it to a dog. Doctor Young, of the University of North Dakota, writes under date of October 9, 1909, that there is a specimen in the university collection, unlabeled, and that rabbits which appear to be infected are seen in North Dakota; he himself has seen such a rabbit. Doctor Shantz, of the Bureau of Plant Industry, has seen such rabbits in Kansas and Colorado, and Mr. E. F. Chilcott of the same Bureau says they are common in South Dakota.

Kaupp's (1910*a*) statement that *M. serialis* is not common in the United States is hardly accurate. In certain Western States it is very common.

The occurrence of the larval parasite in the muscles of its host, especially in the leg muscles, a common site, and its occurrence in such relatively enormous sizes, numbers, or quantities as are given in the more extreme cases of Henry (1909*a*), Morot (1900c), and Mr. Piper, may be looked upon as an adaptation favorable to the parasite, serving to impede the locomotion of the secondary host and so increase the likelihood of its being captured by some carnivore which may serve as the primary host of the parasite. Brandegee (1900a) has also pointed out the presence of an adaptation here.

## THE OCCURRENCES OF THE ADULT MULTICEPS SERIALIS.

The dog is the only host in which the adult *Multiceps serialis* has been found or produced. Thomas's (1889a) attempts to infect cats and ferrets by feeding them the larval cestodes failed, according to Braun (1894a), and a surmise such as that of Brandegee (1890a) that the wolf, coyote, lynx, and fox may act as hosts, has, of course, only the value of a surmise. At the same time, Baillet (1866b) early called attention to the fact that the larval parasite was found in the wild rabbit more commonly than in the domestic rabbit, and surmised that the usual host was some wild carnivore.

Galli-Valerio (1909*a*) failed to develop the adult worm on ingesting two living heads from the larval parasite. The writer also has similarly failed to develop the adult worm on ingesting three living heads from the larval parasite.

*List of occurrences of the adult Multiceps serialis in the dog.*

| Locality. | Authority. | Notes and comments. |
|---|---|---|
| France | Baillet 1858b | By experiment. |
| Do | Baillet 1863a | Do. |
| Do | Baillet 1866b | Found several times. |
| Do | Bertolus and Chauveau 1879a. | One case in a cosmopolitan "dog of the regiment." |
| Italy | Perroncito 1878*a* | Not available; based on Railliet's (18[illegible]a) statement that Perroncito failed to infect sheep from *Cœnurus serialis*. |
| Do | Perroncito 1882a | By experiment. |
| New Zealand | Thomas 1889a | Not available; cited from Braun (1894a); by experiment. |
| France | Neumann 1892a | Several times. |
| Japan | Janson 1893c | By experiment. |
| France | Railliet 1893a | By experiment; claimed that Neumann has also produced it; I can not verify claim. |
| North America | Ward 1895b | Listed. |
| Do | Sommer 1896c | Stated on the authority of Stiles. |
| United States | Ward 1897b | One case out of 20 dogs in Nebraska; others implied. |
| Do | Stiles 1898a | Parasite seen by Stiles. |
| Do | Stevenson 1904b | Two cases out of 35 dogs in Nebraska; 20 specimens. |
| Australia | Cobb 1905*a* | One specimen; identification not positive. |
| United States | Ransom 1905d | Specimen No. 2839 figured. |
| India | Gaiger 1907*a* | By experiment. |
| New South Wales | Johnston 1909*a* | Rare. |
| United States | Hall 1910*β* | This article. |

## ECONOMIC IMPORTANCE.

As has been stated, *Multiceps serialis* is of comparatively little economic importance. It deserves attention from an economic standpoint largely because some scientists, especially the Italian, insist on identifying it with the highly important *M. multiceps*.

Rose (1833a) states, as before mentioned, that when warreners meet with infested rabbits they puncture the bladder, squeeze out the fluid and send the animal to market. According to Martel (1909*α*), this custom of puncturing through the skin of infected rabbits is still in vogue in France. While the idea of eating the parasite is not a pleasing one, the danger from doing so is negligible as the parasite is apparently not transmissible to man, as Galli-Valerio's (1909*α*) and the writer's experiments along this line indicate. Moreau (1909*α*) in a note on abattoir inspection in France, lists muscular cœnurosis of hares and rabbits as sufficient cause for total condemnation of the carcass, but probably this practice would only be followed in such cases as those listed by Morot (1900c), where rabbits were condemned owing to infestation with 11, 20, and 70 cœnuri each. In Morot's cases, a rabbit infested with only 4 cœnuri was returned for food after the removal of the diseased parts. The writer finds that in the western United States the carcasses of rabbits infected with *M. serialis* are thrown away as unfit for food.

## SYNONYMY.

The generic synonymy has already been given under *Multiceps multiceps*.

### Species MULTICEPS SERIALIS (Gervais 1847a) Stiles and Stevenson 1905a.

1828. *E* [*chinococcus*] *veterinorum*(?) of de Blainville 1828a; misdetermination.
1833. *Cœnurus cerebralis* Lamarck and Rudolphi of Rose 1833a; this combination should be attributed to Rudolphi 1808a; error; misdetermination.
1837. *Cænurus cerebralis* of Leblond 1837a; error; misdetermination.
1844. *Cœnurus cerebralis* of Rose 1844a; misdetermination.
1847. *Cœnurus serialis* Gervais 1847a.
1855. *Cœnurus serdalis* Gervais of Goldberg 1855a; in synonomy of *Tænia cœnurus;* this combination should be attributed to Goldberg 1855a; misprint.
1863. *Tænia serialis* (Gervais 1847a) Baillet 1863a; first naming of strobila form.
1863. *Cœnurus cerebralis? leporis cuniculi* Baillet of Diesing 1863b; in synonomy of *Tænia cœnurus;* not at present available, cited from Diesing 1864a, identical; this combination should be attributed to Diesing 1863b.
1863. *Tænia cœnuri cuniculi* Baillet of Diesing 1863b; in synonomy of *Tænia cœnurus;* this combination should be attributed to Diesing 1863b.
1864. *Cœnurus cuniculi* (Diesing 1863b) Cobbold 1864b; name taken from MSS. of Rosé.
1867. *Cœnurus lowzowi* Lindemann 1867a; not available, cited from Lindemann 1868b; same form used once by Braun 1894a.
1868. *Tænia cœnurus* of Cobbold 1867a; error.
1877. *Cœnurus lowtzowi* Lindemann of Pagenstecher 1877a; this combination should be attributed to Pagenstecher 1877a; misspelling.
1877. *Cœnurus nov. spec.* of Pagenstecher 1877a; Pagenstecher refers thus to the form which he identifies as *Cœnurus serialis*.
1877. *Cœnurus scrialis* Gervais of Davaine 1877a; this combination should be attributed to Davaine 1877a; misspelling.
1877. *Tæniaserialis* Baillet of Davaine 1877a; space omitted.
1879. *Arhynchotænia critica* Pagenstecher of Cobbold 1879b; error.
1882. *Cænurus serialis* (Gervais 1847a) Perroncito 1882a.
1882. *Cænurus saerialis* Gervais of Perroncito 1882a; this combination should be attributed to Perroncito 1882a; misspelling.
1882. *Cœnurus serialis* Baillet of Zürn 1882*α*; this combination should be attributed to Gervais 1847a.
1889. "*Cœnurus spec.?* Pagenstecher . . . non *Coen. serialis* Gerv." of von Linstow 1889a.
1894. *Tænia echinococcus* of Herff 1894b; misdetermination.
1897. *Cœnurus lowzowii* Braun 1897a; misspelling.
1897. *Cœnurus lowtzowii* Braun 1897a; misspelling.
1898. *Cenuro serialis* (Gervais 1847a) Bosso 1898*α*.
1900. *Taenia* (*Caenurus*) *socialis* (Bloch 1780a) Gallier 1900a; error.
1901. *C*[*ystotaenia*] *serialis* (Gervais 1847a) Benham 1901a.
1901. *Coenurus serialis* Baill. of Gamble 1901*α*; this combination should be attributed to Gervais 1847a.
1901. T[*aenia*] *serialis* Ball. of Gamble 1901*α*; misprint for Baill.
1901. *Caenurus saerialis* Gervais of Perroncito 1901a; this combination should be attributed to Perroncito 1882a.
1901. *Tenia serialis* (Gervais 1847a) Perroncito 1901a.
1901. *T*[*ænia*] (*Coenurus*) *serialis* Gervais of Vaullegeard 1901a; this combination should be attributed to (Gervais 1847a) Vaullegeard 1901a.
1903. *Tœnia serialis* (Gervais 1847a) Thierry 1903a.

1905. *Cœnuri cuniculi* (Diesing 1863b) Byerly 1905γ; plural.
1905. *Cœnurus serialias* Byerly 1905γ; misprint.
1905. *Cœnurus cerialis* Byerly 1905γ; misprint.
1905. *Cœnurus scrialis* (Gervais 1847a) Davaine 1877a of Stiles and Stevenson 1905a; Davaine 1877a is responsible for specific name; *scrialis* is not Gervais 1847a.
1909. *Cysticercus serialis* (Gervais 1847a) Gray 1909α.
1909. *Tænia serialis* Bailet of Sweet 1909α; misprint for Baillet.
1910. *Cœnurus serialis* Gervals of Johnston 1910α; misprint for Gervais.

Herff's (1894b) statement that *Tænia echinococcus* is very common in the muscles of the jack rabbit in Texas may be considered as probably erroneous. Sommer (1895b) says of this: "Herff must, beyond question, refer to *Cœnurus serialis*." Stiles also, in his review of Herff (1895a), states that this is probably *C. serialis*. Herff's (1895b) later statement that the parasite was a "Compound cyst with tænia heads attached to the walls, or sometimes only hooklets floating in the liquid of the cysts," and his statement that the tapeworm, which he calls *T. echinococcus*, from the dog, was not more than one inch long, are not convincing. So far as available records show, *T. echinococcus* is very rare in the rabbit, and the fact that Herff finds a parasite very common in this host is itself evidence that the parasite was probably not an echinococcus. On the other hand, *M. serialis* is very common in the muscles of rabbits in the United States, and has been reported from Texas. The weight of evidence favors the idea that Herff's "compound cyst" was *M. serialis*. For this reason *Tænia echinococcus* of Herff (1894b) is included as a synonym of *Multiceps serialis*.

## MULTICEPS LEMURIS.

### HISTORICAL SKETCH.

Cobbold (1859d) described a cœnurus from the liver and thorax of *Lemur maco*. (Von Linstow (1878a) has corrected this host name to read *Lemur macaco*.) Later Cobbold (1861e) named this parasite *Cœnurus lemuris*. In macroscopic appearance it does not resemble *M. multiceps* or *M. serialis*, and from the host and location it is more reasonable to accept it as a new species than to attempt to refer it to either of the two species mentioned. It has been listed as certainly or probably distinct by Diesing (1864a), von Linstow (1878a), Railliet (1882a), and Kunsemüller (1903a). On the other hand Moniez (1880a) thinks this form probably belongs with Pagenstecher's (1877a) cœnurus from *Myopotamus coypus* as a specimen of *Multiceps serialis*, and Pagenstecher also states this as probable.

### SYNONYMY.

#### Species MULTICEPS LEMURIS (Cobbold 1861e) Hall 1910β.

1861. *Cœnurus lemuris* Cobbold 1861e.
1880. *Cœnurus lemuri* Cobbold of Mégnin 1880p; this combination should be attributed to Mégnin 1880p; misspelling.

1880. *Cœnurus lemuri* Cobblod of Mégnin 1880p; this combination should be attributed to Mégnin 1880p; misprint for Cobbold.
1894. *Cœnurus lemoris* Cobb. 1861 of Braun 1894a; this combination should be attributed to Braun 1894a.

## MULTICEPS POLYTUBERCULOSUS.

### HISTORICAL SKETCH.

Mégnin (1879d) describes a cœnurus from the leg of the jerboa (*Dipus sagitta*). The following year Mégnin (1880d) named it *Cœnurus polytuberculosus* and published a more adequate description. From the structure of the opaque, tuberculate external coat and of the hooks it seems reasonably certain that this form must be retained as a distinct species. Reinitz (1885a) and Braun (1897a) agree that this parasite is not *M. serialis,* and Kunsemüller (1903a) does not think it likely.

### SYNONYMY.

**Species MULTICEPS POLYTUBERCULOSUS (Mégnin 1880d) Hall 1910β.**

1879. "Cœnure polytuberculeux" of Mégnin 1879d.
1880d. *Cœnurus polytuberculosus* Mégnin 1880d.
1894. *Cysticercus polytuberculosus* Mégnin [1880d] of Braun 1894a; this combination should be attributed to (Mégnin 1880d) Braun 1894a.
1903. *Cœnurus tuberculosus* Mégnin of Kunsemüller 1903a; this combination should be attributed to Kunsemüller 1903a.

## MULTICEPS SPALACIS.

### HISTORICAL SKETCH.

Note has already been made of Diesing's (1850a) cœnurus "ex *Ipalacis capensis*," tentatively considered as *Cœnurus cerebralis* by Diesing. In a later article Diesing (1864a) corrected the host name to *Spalax capensis* and gave a general description, of which the only fact of interest is the occurrence of a single circlet of hooks. Such a feature was mentioned by Lindemann (1867a) as occurring in his *Cœnurus lowzowi* and was found once by Pagenstecher (1877a) in his *M. serialis* from *Myopotamus coypus.* The location of the parasite is not given, nor are there any other data of value in species determination, so in the absence of other similar records from this host the species is retained on Diesing's determination and under the name given by Moniez (1880a).

A discussion as to the probable host has already been given on p. 40.

### SYNONYMY.

**Species MULTICEPS SPALACIS (Moniez 1880a) Hall 1910β.**

1850. *Cœnurus* Diesing 1850a.
1878. *Cœnurus spec.*? of von Linstow 1878a.
1880. *Cœnurus spalacis* Moniez 1880a.
1902. *Cœnurus spalacis* Dies. of von Linstow 1902q; this combination should be attributed to Moniez 1880a.

## CYSTICERCUS BOTRYOIDES (species inquierenda).

### HISTORICAL SKETCH.

Boettcher (1862a), according to Braun (1894a), describes a *Cysticercus botryoides* from the back muscles of a rabbit. The form is said to apparently arise by budding from a parent vesicle. It has been considered as *Cœnurus serialis* by Railliet (1882a). Reinitz (1885a) does not consider it as *M. serialis*, owing to differences in macroscopic appearance and hook form. Von Linstow (1878a) lists it as "*Cœnurus spec.?* (*Cœnurus cerebralis* Rud.?)." Leuckart (1865a) says that since the size, form, and number of the hooks agree with those of *Cœnurus* [species not specified] there are no grounds for making a new species. Braun (1897a) doubts whether this was a cœnurus at all, and considers it a budding cysticercus, and Kunsemüller (1903a) agrees with Braun. Inasmuch as the original description is not available, and the authorities cited disagree as to the identity and even as to the generic position of this form, it has been retained here under the original name as a species inquierenda.

### SYNONYMY.

**Species CYSTICERCUS BOTRYOIDES Boettcher 1862a.**

1862. *Cysticercus botryoides* Boettcher 1862a; not available; cited from Braun 1894a.
1889. *Cysticercus botryoides* Reinitz of von Linstow 1889a; this combination should be attributed to Boettcher 1862a.
1889. *Cœnurus spec.* Boettcher of von Linstow 1889a.
1896. *C*[*œnurus*] *botryoides* Böttcher of Braun 1896d; this combination should be attributed to (Boettcher 1862a) Braun 1896d.

## ACEPHALOCYSTIS OVIS TRAGELAPHI (species inquierenda).

### HISTORICAL SKETCH.

Cobbold (1861e), in a list of entozoa, lists *Acephalocystis ovis tragelaphi* from *Ovis tragelaphus*, with the following note: "A solitary specimen filled with clear serous fluid. Probably an aborted Cœnurus. Spherical; 1 inch in diameter."

In the absence of any morphological characteristics which could possibly relate this specimen to the genus *Multiceps*, and with no statement as to the location on which to base even a surmise as to the likelihood of its being a cœnurus, it would be useless to pass judgment on this specimen.

### SYNONYMY.

**ACEPHALOCYSTIS OVIS TRAGELAPHI Cobbold 1861e.**

1861. *Acephalocystis tragelaphi* Cobbold 1861e.

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636.

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BUREAU OF ANIMAL INDUSTRY.—BULLETIN 126.
A. D. MELVIN, CHIEF OF BUREAU.

# THE BACTERIOLOGY OF COMMERCIALLY PASTEURIZED AND RAW MARKET MILK.

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# LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
*Washington, D. C., July 8, 1910.*

Sir: I have the honor to transmit herewith, and to recommend for publication as a bulletin of this Bureau, a manuscript entitled "The Bacteriology of Commercially Pasteurized and Raw Market Milk," by S. Henry Ayers, bacteriologist, and William T. Johnson, Jr., scientific assistant, in the Dairy Division of this Bureau.

Respectfully,

A. D. Melvin,
*Chief of Bureau.*

Hon. James Wilson,
*Secretary of Agriculture.*

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# THE BACTERIOLOGY OF COMMERCIALLY PASTEURIZED AND RAW MARKET MILK.

## INTRODUCTION.

Pasteurization is a term which needs no explanation, nor is it necessary to review its history. The general public has been liberally informed during the past two years as to what the pasteurization of milk means. It is true that newspaper articles often are misleading, and the minds of the people have been led to favor or oppose pasteurization largely through popular articles in the press or advertisements of dairies, which either point out the value of or the danger from pasteurized milk.

But the question as to pasteurization is not unsettled in the public mind alone; the subject is one which has caused a division of opinion also in the medical profession and in the scientific world. There are those who oppose pasteurization and those who are in favor of it. Some oppose it under any condition; others admit that it should be resorted to under exceptional conditions.

It may be asked with fairness why such a division of opinion exists among even those who have made milk problems a life study. Only one answer can be given, namely, that the subject of pasteurization has as yet been touched only upon the surface, notwithstanding the numerous valuable pieces of research work which have been published concerning it.

## MODERN THEORIES OF PASTEURIZATION.

Since the pasteurization of milk has become extensively practiced and is advocated by health officers and other authorities on milk, obviously there must be some advantages connected with the process. Some of the points of value in pasteurization which serve as a foundation for the opinions of those who advocate the process may be considered first.

### ADVANTAGES CLAIMED FOR THE PROCESS.

When the rôle that raw milk plays as a vehicle of disease and the ease with which it may become infected are considered, obviously the principal advantage of pasteurization is in the destruction of pathogenic organisms. It has been shown by many investigators that *Bacillus tuberculosis*, *B. typhi*, *B. diphtheriæ*, and the dysentery bacillus are destroyed when milk is pasteurized at 60° C. (140° F.) for twenty minutes. While epidemics caused by infected milk may occur only at rare intervals, any possible means of protection seems justifiable. Sanitary inspection has greatly improved the milk supply, but under present conditions its scope is limited by the magnitude of the problem. The aim of sanitary supervision is to improve the conditions under which milk is produced. The goal of the struggle for improved milk is the production of clean milk from tuberculin-tested herds, preferably produced by a few large dairy farms which are under the supervision of competent men, rather than on a large number of small farms. Granting, however, that ideal conditions can be ultimately reached, we are nevertheless confronted by entirely different conditions at the present time. Certified milk is produced in relatively small amounts in this country, and its cost of production makes its price prohibitive for a large majority of people. A good grade of clean milk may be furnished to a city where the consumption of milk is small enough to allow constant inspection of the dairy farms supplying the city. With large cities the problem is different. For example, take the case of New York, where the milk supply comes from approximately 35,000 farms located in 6 different States and is shipped from about 700 dairies. With milk coming from such a large area, constant sanitary supervision is an immense problem. In such a case the general conditions on the farms may be improved, but to expect in the immediate future to have all the milk come from tuberculin-tested cows and to have inspection of the farms efficient enough to prevent the possibility of typhoid infection is beyond reason.

The frequency of tubercle bacilli in market milk is well known. Anderson[3][a] in an examination of market milk in Washington, D. C., has shown that milk from approximately 11 per cent of the dairies examined contained tubercle bacilli virulent for guinea pigs. Examinations even of certified milk sometimes show the presence of the tubercle bacillus.

The number of epidemics of typhoid fever traced to milk is striking. Schüder[23] collected from the literature statistics of 650 typhoid epidemics, the supposed cause of which had been reported. Of these 462 were reported as spread by water, 110 by milk, and 78 by other agents. Lumsden[13] gives figures showing the theoretical number of typhoid cases in Washington during one year which may be expected to be caused by infected milk. According to his figures 1,000 farms supply Washington, and by estimating seven persons living at each farm and considering that in the United States every year about 1 in every 300 persons has typhoid fever, then some 25 cases per year may be expected to occur on dairy farms supplying the city.

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[a] The figures refer to the list of references on pages 62 and 63.

It is easy to see how typhoid on farms may be readily conveyed by means of milk to the city, where epidemics may result. Even with sanitary supervision of the farms it is hard and practically impossible to prevent occasional infection of the milk. Frequently cases of typhoid fever are not recognized up to the second or third week of illness, until which time no precautions are taken. In many instances mild cases are unattended by a physician and even in some cases may not be recognized. Persons who have recovered from the disease but who are still discharging typhoid bacilli in their stools and urine may directly infect the milk while handling it.

The rôle of typhoid carriers in the spread of the disease in relation to the infection of milk is attracting attention. Albert[1] has shown that about 75 per cent of all carriers are women, and that, almost without exception, the carriers have been employed in some occupation, as baker, cook, or handler of milk, which has enabled them to transmit typhoid bacilli to substances used as food by others. He says that in some cases carriers had typhoid but a short time previous, and in other cases as long as ten, thirty, and even fifty-two years. He estimates that 1 in every 500 adults is a chronic carrier, while it has been estimated that there are about one-half as many carriers in a community as there are cases of typhoid fever. It is evident that to guard against chances of typhoid infection from an inspected dairy it may be necessary to have a medical examination of the dairymen.

Numerous cases of epidemics of diphtheria and scarlet fever, as well as more obscure diseases, have been traced to milk. In this connection Freeman[6] states:

> Diphtheria has apparently been spread by the best of our milk supplies. What protection have we against this in any raw milk? Virulent diphtheria bacilli exist in the throats of many healthy persons, and, though in our best dairies we have some medical supervision, no supervision could be practically enforced that would protect the milk from a beginning diphtheria or a healthy diphtheria bacillus carrier.

The numbers of bacteria in milk are of great importance in relation to intestinal diseases in children. The establishment of pasteurizing plants by Straus in various cities, where pasteurized milk is supplied to children of the poor, who are ordinarily compelled to use a dirty milk high in bacteria, as well as the use of commercially pasteurized milk, has done much to lower the infantile death rate. It seems to be the number of bacteria rather than the species which are concerned. Park[15] says:

> After five years of effort to discover some relation between special varieties of bacteria found in milk and the health of children the conclusion has been reached that neither through animal tests nor the isolation from the milk of sick infants have we been able to establish such a relation.

Kenwood[11] believes that the pasteurization of the public supply affords a readily available means of bringing about a reduction of infantile sickness, even if the maximum is conceded to those who discredit it. Lederle[12] in stating the advantages of pasteurized milk states:

> The great benefits derived from its use in infant feeding in hospitals, infant-milk depots, and in private practice will be attested by most physicians.

The destruction of a large percentage of the bacteria during pasteurization results in an improved keeping quality, which is of importance from a commercial as well as a hygienic point of view.

The principal advantages of pasteurization may be summarized as follows:

1. Protection from infection with the diseases usually transmitted by milk.
2. Reduction of bacteria and, as a consequence, of the infantile death rate.
3. The enhancing of the keeping quality of the milk.

It might seem that the advantages of pasteurization mentioned in the preceding pages were of sufficient value to advocate its general application. Many authorities, however, do not favor pasteurization. Some of the objections may be considered next.

### OBJECTIONS TO PASTEURIZATION.

One of the most serious objections to pasteurized milk is that it is believed to putrefy rather than sour, due to the destruction of lactic-acid bacteria which produce acid in raw milk. The destruction of the acid bacteria is believed to result in the unhindered growth of undesirable organisms which may form toxins or other poisonous products, thus making the milk unfit for human consumption, especially in the case of young infants. This view dates back to the investigations of Flügge,[5] whose work on pasteurized milk heated to 70° C. (158° F.) for thirty minutes demonstrated the presence of spore-forming, peptonizing bacteria which developed in the milk and formed highly toxic substances. Weber,[24] however, found only three of these types of bacteria during an examination of 150 samples of commercial sterilized milk. Farrington and Russell[4] state that in numerous experiments they have found the thermal death point of the lactic-acid bacteria to be in the neighborhood of 57.2 to 60° C. (135 to 140° F.) where the exposure was for ten minutes. Russell and Hastings[21] state, in their book on Agricultural Bacteriology, that—

> The lactic bacteria do not form spores, and hence are easily killed if milk is heated. If milk is pasteurized and subsequently kept free from lactic bacteria, it will not sour, but will putrefy, due to the development of the spores not killed by the heating. Often the first sign of spoiling in pasteurized milk is the appearance of a bitter or other undesirable taste. Frequently it does not curdle for a long time. One of

> the dangers in the use of pasteurized milk is the fact that the consumer has no way of telling how old it is. It may appear normal in every way and yet be harmful to the health.

Revis, in a discussion of a paper by Kenwood[11], makes the statement that raw milk never putrefies, pasteurized milk always does. Lederle[12] believes that with the destruction of the ordinary lactic-acid bacteria, which constitute the danger signal of old milk, the souring process is interfered with, and that more serious changes may take place without the knowledge of the consumer. Freudenreich[7] points out the danger of allowing pasteurized milk to stand at high temperatures, due to the growth of spores of the hay and potato bacillus which are not killed during pasteurization. Jensen[9] considers that the use of temperatures suitable to kill *Bacillus tuberculosis* destroys also the lactic-acid bacteria, which, under normal conditions in raw milk, prevent undesirable fermentations. In consequence the commercially pasteurized milk becomes more dangerous than raw milk. He believes that the degree of acidity of raw milk indicates its freshness, while the most dangerous alterations in pasteurized milk often are not visible macroscopically and escape those who control its consumption.

Rickards[17] states:

> Pasteurized milk seems to keep longer, but eventually acquires a strong odor, and really may be said to decompose rather than sour. In nearly every instance we found that pasteurized milk, even when heavily loaded with bacteria, did not decompose until after the nonpasteurized milk taken at the same time had curdled. That such milk is unfit for food, especially for babies, goes without saying.

In connection with this objection to pasteurization Doctor Harrington, in a discussion of a paper by Rotch,[19] states:

> Again, it will make possible the carrying along of milk until, although not sour, it may become more or less poisonous. I believe that dirty milk should be allowed to stay dirty, so that it will sour more quickly, rather than that the lactic-acid ferments shall be destroyed and the commercial life of the milk be prolonged, thus permitting those organisms which are not affected by heat and which are believed to elaborate toxic substances to go on making the milk dangerous.

Another objection to pasteurization is brought out by Pennington and McClintock,[16] who ask this question:

> When milk before pasteurization shows a count of over 1,000,000, is it desirable to permit in a food the toxins and products of metabolism of these many generations of organisms, even though they themselves may be reduced to a very few hundred thousand at the expense frequently of milk enzyms and probably other substances closely connected with its food value and keeping qualities?

Rotch[19] expresses the same sentiment when he says:

> It is a fact that certain organisms are killed by pasteurization, but we can not kill the toxins of these organisms by heat. Simply pasteurizing or sterilizing will still allow the milk to contain elements which are exceedingly dangerous to those who drink it, and especially where young infants are concerned.

Rotch further states that the improper methods of heating now in vogue preserve the milk only some five or six hours longer than the normal raw milk, and that the commercially pasteurized milk after it has turned sour seems to be in a great deal worse condition than when natural souring took place. It may be noted, however, that his views are based on clinical observations rather than experimental data.

Some object to pasteurized milk on account of the careless methods of handling after pasteurization. Pennington and McClintock[16] believe that from the quantitative count alone it would scarcely seem worth while to pasteurize milk of fair quality, since the contamination acquired in bottling is very often sufficient to overbalance the original germ content of the milk. They found that in commercial pasteurizing plants very low counts could be obtained from milk in the heating coils but that it was contaminated in the cooling and bottling, so that sometimes the final count was higher than that of the original milk.

It is greatly feared by some that the adoption of pasteurization will interfere with the extension of sanitary supervision. This opinion is well expressed in the discussion of Rotch's[19] paper by Harrington, who says:

> Pasteurization will put back improvements on the source of the supply and will encourage dirty habits, the farmer understanding that it is not necessary to be so particular since the dirt that gets in is going to be cooked and made harmless.

Another serious objection is that unscrupulous dealers may repasteurize their milk or pasteurize an old milk which ordinarily would not be marketable. It is safe to say, however, that such cases are exceptional. It is often stated also that bacteria increase more rapidly in pasteurized milk than in raw milk, and considering the possibility of infections as shown by Pennington and McClintock[61] the more rapid growth presents a serious objection to pasteurized milk. St. John and Pennington[22] have shown in a few experiments that a more rapid increase in bacterial growth takes place in pasteurized reinfected milk than in raw milk. Their conclusions are based on the ratio of increase. Rickards [17] working on commercially pasteurized milk concludes that on the average bacteria will increase four times as fast in pasteurized milk as in raw milk when kept for twenty-four hours at the temperature of the ice box. His conclusions are drawn from the following table and are based on the ratio of bacterial increase:

| | Unpasteurized milk, average count. | Pasteurized milk, average count. | Number of samples. |
|---|---|---|---|
| First day | 1,087,000 | 44,000 | 87 |
| After 24 hours in ice box | 22,617,000 | 3,691,000 | .......... |
| Per cent increase | 2,100 | 8,400 | .......... |
| Ratio | 1 | 4 | .......... |

The change in the chemical constituents of milk produced by heat is sometimes the basis of objection to pasteurized milk. Chemical investigations have shown that high temperatures do produce changes in the composition of milk, but the question of the action of lower temperatures for a long period of heating, such as is employed in the "holder" process, is one which demands further study.

As to the effect of feeding heated milk to children, here again authorities are divided. Some believe that malnutrition can often be attributed to the use of pasteurized milk and that rickets and scurvy result from its use. Most authorities, however, agree that pasteurized milk is not injurious, at least as far as the chemical changes produced by heating are concerned.

The objections to pasteurization which are generally accepted as being well founded may be summarized as follows:

1. It is believed that the lactic-acid bacteria in raw milk, which eventually sour the milk, exert a restraining influence on the peptonizing bacteria, which would otherwise cause the putrefaction of the milk. In other words, when milk is pasteurized and subsequently kept free from lactic-acid bacteria, which are easily killed by heat, it will not sour but will putrefy, due to the development of peptonizing bacteria, the spores of which are not destroyed during pasteurization. The peptonizing bacteria, when freed from the restraining influence of the lactic-acid organisms, may increase to large numbers and produce toxins and poisonous decomposition products.
2. The pasteurization of dirty milk, while reducing the bacterial numbers, does not destroy the toxins or other products of bacterial growth.
3. Careless methods of handling after pasteurization may result in serious contamination of the milk.
4. Pasteurization may be used simply to cover up dirty milk; it may encourage dirty methods in production and retard the extension of sanitary supervision.
5. Milk which has not been sold may be pasteurized, or even repasteurized, and its faults hidden.
6. Bacteria may increase more rapidly in pasteurized milk than in raw milk.
7. Undesirable changes may be produced by heating which result in making the milk less digestible, particularly in the case of infants.

It will be seen from the foregoing that much is to be said on both sides of the question, and that further investigation is required, which must be sufficiently thorough and deep so that the conclusions arrived at may be generally accepted.

## OBJECT OF THIS INVESTIGATION.

The general object of this work has been to study the bacterial flora of commercially pasteurized and raw market milk. The term "commercially pasteurized" signifies all kinds of such milk and is not intended to indicate the "flash" process, which is distinguished in some cities from perfectly pasteurized milk (meaning that pasteurized by the "holder" process). The endeavor has been made to study the bacteria in the two kinds of milk, pasteurized and raw, when fresh and on each succeeding day as long as the milk was fit for consumption. The special objects have been to determine to what extent the lactic-acid bacteria were destroyed, and to what extent the peptonizing bacteria developed, and to compare the development of various groups of bacteria in pasteurized and raw mlik.

## METHODS.

The standards proposed by the committee on standard methods for water analysis[2] have been followed almost exactly, the only change being made in substituting Liebig's beef extract for beef infusion in the preparation of nutrient broth. Two per cent lactose was used in both litmus lactose agar and litmus lactose gelatin. The total count of the milk samples was made on litmus lactose agar plus 1 (Fuller's scale), incubated at 30° C. (86° F.), and recorded after forty-eight hours. On the other hand, the differential count was made from litmus lactose gelatin incubated at 18° C. (64.4° F.) for four days. In using this low temperature the results were more consistent; the low temperature holds the peptonizers in check and gives other forms a chance to develop characteristic colonies. In some cases the gelatin plates had to be counted before four days on account of the large number of liquefying colonies; in other cases it was possible to let the plates incubate as long as five days.

## PASTEURIZATION EXPERIMENTS.

The larger part of the work herein described has been with commercial market milk, but it was thought advisable to carry on a few additional experiments in which the pasteurizing process could be controlled. Accordingly, during the summers of 1908 and 1909 experiments were carried on at the field laboratory of the Dairy Division. Experiments were made, using both the "flash" process, which consists of heating flowing milk for from thirty to forty seconds and then cooling, and the "holder" process, where the milk is heated in a tank and held for thirty minutes before cooling.

## COMPARISON OF RAW MILK AND MILK PASTEURIZED BY THE "FLASH" PROCESS.

A small pasteurizer of the "flash" type was used in these experiments, and the data obtained are tabulated in Table 1 following.

### EXPERIMENT WITH MILK HELD AT 10° C. (50° F.).

The milk used in this experiment was held in the ice chest at 10° C. (50° F.) after pasteurization. The raw milk, it will be noticed, was high in bacteria, as it was produced for butter-making purposes and little care was taken to keep the bacterial numbers down by low temperatures. In each experiment a sample of raw milk was taken in steamed milk bottles together with a sample of the same milk after pasteurization. The samples after collection were plated on litmus lactose agar and incubated for forty-eight hours at 30° C. (86° F.), when the total count was made. The peptonizing bacteria were counted on litmus lactose gelatin incubated at 18° C. (64.4° F.) for four days. The acidity was determined daily and is expressed in percentage of lactic acid.

The milk was examined in this manner until unfit for use. A word of explanation is required concerning the higher count in milk pasteurized at high temperatures than in that heated to lower temperatures; for example, sample No. 11 heated at 82.2° C. (180° F.) shows a higher count after pasteurization than milk heated at any of the other temperatures. This is probably explained by the method of heating. In running a series of different temperatures the highest degree was used first, and while the milk was still flowing through the machine the temperature was lowered in order to obtain samples pasteurized at the other temperatures. The high count was evidently due to the washing out of the machine and the cooler with the milk. It may be mentioned in this connection that the method of collecting samples could not have been changed without interfering with the daily work in the creamery where the pasteurizer was located, and since the method affected only the samples heated at the temperatures higher than those ordinarily used in commercial work it was not considered necessary to repeat the experiments. In all the experiments the machine proved very efficient; the total bacteria in pasteurized milk remained low during the first two days and in many cases for three days.

The difference in temperature of heating seemed to show very little effect on the total numbers after four days. Bacterial reduction during pasteurization may vary greatly with the same temperature in different samples. Compare sample No. 1, raw milk, 1,500,000 bacteria per c. c., reduced to 34,000 in the pasteurized milk, with sample No. 15, raw milk, 13,472,000, reduced to 1,600 per c. c. That means an efficiency in the first case of 97.7 per cent against 99.9 per cent in the last case. The difference in efficiency may not be due to careless methods of controlling the temperature or to contamination, but may be caused by the larger proportion of heat-resisting species of bacteria or bacteria in their spore form.

TABLE 1.—*Comparison of raw and pasteurized ("flash" process) milk held 10° C. (50° F.).*

| Sample No. | Kind of milk. | Temperature of pasteurization. | First day. | | | Second day. | | |
|---|---|---|---|---|---|---|---|---|
| | | | Acidity. | Total bacteria per c. c. | Peptonizing bacteria per c. c. | Acidity. | Total bacteria per c. c. | Peptonizing bacteria per c. c. |
| 1 | Raw | | 0.16 | 1,500,000 | 100,000 | 0.18 | 4,500,000 | 400,000 |
| | Pasteurized | 76.7° C. (170° F.) | .17 | 34,000 | 1,500 | .17 | 42,000 | 9,000 |
| 2 | Raw | | .16 | 183,000 | 32,000 | .17 | 2,600,000 | 360,00 |
| | Pasteurized | 79.45° C. (175° F.) | .15 | 4,600 | 1,100 | .15 | 5,200 | 2,000 |
| 3 | Raw | | .15 | 1,170,000 | 30,000 | .16 | 53,200,000 | 1,000,000 |
| | Pasteurized | 82.2° C. (180° F.) | .14 | 209,000 | 1,000 | .14 | 367,000 | 20,000 |
| 4 | Raw | | .15 | 10,200,000 | 2,700,000 | .19 | 86,000,000 | 1,000,000 |
| | Pasteurized | 85° C. (185° F.) | .14 | 350,000 | 5,000 | .14 | 5,930,000 | 30,000 |
| 5-6 | Raw | | .18 | 6,900,000 | 500,000 | .22 | 156,000,000 | 4,700,000 |
| 5 | Pasteurized | 71.1° C. (160° F.) | .16 | 3,630,000 | 100,000 | .16 | 16,000,000 | 30,000 |
| 6 | do | 65.6° C. (150° F.) | .16 | 790,000 | ........... | .16 | 6,500,000 | 100,000 |
| 7-11 | Raw | | .18 | 12,800,000 | 2,600,000 | .20 | 76,600,000 | 400,000 |
| 7 | Pasteurized | 60° C. (140° F.) | .18 | 62,150 | 100 | .18 | 199,000 | 44,000 |
| 8 | do | 65.6° C. (150° F.) | .18 | 36,700 | 500 | .18 | 447,000 | 280,000 |
| 9 | do | 71.1° C. (160° F.) | .17 | 15,000 | 500 | .17 | 30,000 | ........... |
| 10 | do | 76.7° C. (170° F.) | .16 | 9,000 | 1,100 | .16 | 98,000 | ........... |
| 11 | do | 82.2° C. (180° F.) | .14 | 562,000 | 6,000 | .14 | 870,000 | 10,000 |
| 12-16 | Raw | | .18 | 13,472,000 | ........... | .20 | 102,900,000 | 100,000 |
| 12 | Pasteurized | 60° C. (140° F.) | .16 | 3,450 | 100 | .17 | 7,100 | 400 |
| 13 | do | 65.6° C. (150° F.) | .15 | 2,200 | ........... | .16 | 5,600 | 100 |
| 14 | do | 71.1° C. (160° F.) | .15 | 600 | ........... | .14 | 2,000 | 100 |
| 15 | do | 76.7° C. (170° F.) | .14 | 1,600 | ........... | .16 | 3,750 | 100 |
| 16 | do | 82.2° C. (180° F.) | .14 | 29,300 | 900 | .15 | 101,000 | 400 |

| Sample No. | Kind of milk. | Temperature of pasteurization. | Third day. | | | Fourth day. | | |
|---|---|---|---|---|---|---|---|---|
| | | | Acidity. | Total bacteria per c. c. | Peptonizing bacteria per c. c. | Acidity. | Total bacteria per c. c. | Peptonizing bacteria per c. c |
| 1 | Raw | | 0.19 | 38,000,000 | 400,000 | 0.29 | 49,500,000 | 600,000 |
| | Pasteurized | 76.7° C. (170° F.) | .17 | 144,000 | 7,000 | .17 | 3,600,000 | 400,000 |
| 2 | Raw | | .18 | 10,300,000 | 1,500,000 | .18 | 47,000,000 | 4,000,000 |
| | Pasteurized | 79.45° C. (175° F.) | .16 | 32,800 | 3,000 | .16 | 2,600,000 | 10,000 |
| 3 | Raw | | .22 | 379,000,000 | 7,900,000 | .37 | 531,000,000 | 2,000,000 |
| | Pasteurized | 82.2° C. (180° F.) | .16 | 8,740,000 | 170,000 | .17 | 82,800,000 | ........... |
| 4 | Raw | | .36 | 500,000,000 | 200,000 | .64 | 1,400,000,000 | 10,000,000 |
| | Pasteurized | 85° C. (185° F.) | .19 | 206,000,000 | 1,000,000 | .57 | 849,000,000 | 3,000,000 |
| 5-6 | Raw | | .45 | 1,460,000,000 | 10,000,000 | .64 | ........... | ........... |
| 5 | Pasteurized | 71.1° C. (160° F.) | .17 | 48,000,000 | 500,000 | .19 | 128,000,000 | 2,000,000 |
| 6 | do | 65.6° C. (150° F.) | .17 | 98,000,000 | 700,000 | .23 | 205,000,000 | 2,000,000 |
| 7-11 | Raw | | .34 | 380,000,000 | 1,000,000 | .64 | 980,000,000 | ........... |
| 7 | Pasteurized | 60° C. (140° F.) | .18 | 370,000 | ........... | .17 | 5,650,000 | 100,000 |
| 8 | do | 65.6° C. (150° F.) | .18 | 970,000 | 100,000 | .18 | 13,100,000 | ........... |
| 9 | do | 71.1° C. (160° F.) | .17 | 810,000 | 30,000 | .17 | 13,500,000 | 100,000 |
| 10 | do | 76.7° C. (170° F.) | .16 | 70,000 | ........... | .16 | 6,700,000 | 200,000 |
| 11 | do | 82.2° C. (180° F.) | .15 | 11,200,000 | 50,000 | .15 | 22,000,000 | 400,000 |
| 12-16 | Raw | | .43 | 370,000,000 | 100,000 | .54 | 756,000,000 | ........... |
| 12 | Pasteurized | 60° C. (140° F.) | .16 | 293,000 | 900 | .18 | 3,260,000 | 30,000 |
| 13 | do | 65.6° C. (150° F.) | .16 | 52,000 | 1,000 | .17 | 982,000 | 9,000 |
| 14 | do | 71.1° C. (160° F.) | .17 | 97,000 | 1,000 | .17 | 3,480,000 | 10,000 |
| 15 | do | 76.7° C. (170° F.) | .15 | 45,000 | 100 | .15 | 671,000 | 3,000 |
| 16 | do | 82.2° C. (180° F.) | .15 | 375,000 | 3,000 | .16 | 3,970,000 | 30,000 |

**TABLE 1.**—*Comparison of raw and pasteurized ("flash" process) milk held 10° C. (50° F.)*—Continued.

| Sample No. | Kind of milk. | Temperature of pasteurization. | Fifth day. | | | Sixth day. | | |
|---|---|---|---|---|---|---|---|---|
| | | | Acidity. | Total bacteria per c. c. | Peptonizing bacteria per c. c. | Acidity. | Total bacteria per c. c. | Peptonizing bacteria per c. c. |
| 1 | Raw | | 0.37 | 131,400,000 | 400,000 | 0.63 | 212,000,000 | 200,000 |
| | Pasteurized | 76.7° C. (170° F.) | .18 | 4,850,000 | 1,600,000 | .33 | 65,500,000 | 13,000,000 |
| 2 | Raw | | .24 | 318,000,000 | 3,600,000 | .44 | 454,000,000 | |
| | Pasteurized | 79.45° C. (175° F.) | .16 | 27,200,000 | 150,000 | .18 | 160,000,000 | |
| 3 | Raw | | .64 | 790,000,000 | | .67 | | |
| | Pasteurized | 82.2° C. (180° F.) | .40 | 740,000,000 | | .64 | | |
| 4 | Raw | | .71 | | | | | |
| | Pasteurized | 85° C. (185° F.) | .66 | | | | | |
| 5-6 | Raw | | | | | | | |
| 5 | Pasteurized | 71.1° C. (160° F.) | .34 | 326,000,000 | | .63 | | |
| 6 | do | 65.6° C. (150° F.) | .60 | 650,000,000 | | .69 | | |
| 7-11 | Raw | | .68 | | | | | |
| 7 | Pasteurized | 60° C. (140° F.) | .16 | 28,600,000 | 500,000 | .22 | 72,000,000 | 1,000,000 |
| 8 | do | 65.6° C. (150° F.) | .16 | 44,000,000 | 700,000 | .18 | 91,000,000 | 2,000,000 |
| 9 | do | 71.1° C. (160° F.) | .18 | 35,800,000 | 1,200,000 | .33 | 79,000,000 | 2,000,000 |
| 10 | do | 76.7° C. (170° F.) | .17 | 28,600,000 | 800,000 | .20 | 57,000,000 | 2,000,000 |
| 11 | do | 82.2° C. (180° F.) | .17 | 100,000,000 | 1,100,000 | .31 | 488,000,000 | 7,000,000 |
| 12-16 | Raw | | .63 | 1,019,000,000 | | .63 | 960,000,000 | |
| 12 | Pasteurized | 60° C. (140° F.) | .18 | 65,500,000 | 700,000 | .21 | 348,000,000 | 1,000,000 |
| 13 | do | 65.6° C. (150° F.) | .18 | 32,100,000 | 300,000 | .19 | 96,000,000 | 1,000,000 |
| 14 | do | 71.1° C. (160° F.) | .17 | 15,000,000 | 140,000 | .19 | 227,000,000 | 1,500,000 |
| 15 | do | 76.7° C. (170° F.) | .16 | 9,000,000 | 100,000 | .18 | 45,500,000 | 600,000 |
| 16 | do | 82.2° C. (180° F.) | .18 | 19,600,000 | 1,100,000 | .27 | 597,000,000 | 3,000,000 |

| Sample No. | Kind of milk. | Temperature of pasteurization. | Seventh day. | | | Remarks. |
|---|---|---|---|---|---|---|
| | | | Acidity. | Total bacteria per c. c. | Peptonizing bacteria per c. c. | |
| 1 | Raw | | 0.79 | | | Slightly sour on fifth day. |
| | Pasteurized | 76.7° C. (170° F.) | .52 | 293,000,000 | 8,000,000 | Slightly sour on seventh day. |
| 2 | Raw | | .45 | 488,000,000 | 300,000 | Slightly bitter on sixth day; slightly sour on seventh day. |
| | Pasteurized | 79.45° C. (175° F.) | .24 | 240,000,000 | 24,000,000 | Slightly bitter on sixth day; slightly sour on eighth day. |
| 3 | Raw | | | | | Curdled on sixth day. |
| | Pasteurized | 82.2° C. (180° F.) | | | | Slightly sour on fifth day. |
| 4 | Raw | | | | | Sour on fourth day. |
| | Pasteurized | 85° C. (185° F.) | | | | Do. |
| 5-6 | Raw | | | | | Curdled and sour on fourth day. |
| 5 | Pasteurized | 71.1° C. (160° F.) | | | | Curdled and sour on sixth day. |
| 6 | do | 65.6° C. (150° F.) | | | | Slightly sour on fifth day. |
| 7-11 | Raw | | | | | Sour on fourth day; coagulated on sixth day. |
| 7 | Pasteurized | 60° C. (140° F.) | .46 | 230,000,000 | 36,000,000 | Slightly bittor on sixth day. sour on eighth day. |
| 8 | do | 65.6° C. (150° F.) | .27 | 235,000,000 | 17,000,000 | Do. |
| 9 | do | 71.1° C. (160° F.) | .45 | 301,000,000 | 29,000,000 | Do. |
| 10 | do | 76.7° C. (170° F.) | .35 | 570,000,000 | 29,000,000 | Do. |
| 11 | do | 82.2° C. (180° F.) | .47 | 612,000,000 | 2,000,000 | Do. |
| 12-16 | Raw | | 69 | | | Sour on fourth day. |
| 12 | Pasteurized | 60° C. (140° F.) | .29 | | | Slightly sour on eighth day. |
| 13 | do | 65.6° C. (150° F.) | | | | Sweet on eighth day. |
| 14 | do | 71.1° C. (160° F.) | .22 | | | Do. |
| 15 | do | 76.7° C. (170° F.) | .19 | | | Do. |
| 16 | do | 82.2° C. (180° F.) | .38 | | | Slightly sour on eighth day. |

### THE INCREASE IN PEPTONIZING BACTERIA.

The peptonizing bacteria in milks held at 10° C. (50° F.) are shown in Table 2.

The most striking feature is the low number of peptonizers, especially during the first three days; in every case the peptonizers represented only a small percentage of the total bacteria. This may be seen by comparison with Table 1.

During the first three days the peptonizing bacteria in the pasteurized milk were very low as compared with those in the raw milk, and were much lower on the fourth and fifth days in sample No. 2, and also on the fourth day in sample No. 4. The low count of peptonizers in the raw milk was undoubtedly due to the large numbers of lactic-acid bacteria, which exercise a restraining influence on the development of the peptonizing forms. These figures indicate, as far as these experiments are concerned, that the peptonizing bacteria do not play the important part in pasteurized milk that is credited to them.

TABLE 2.—*Number of peptonizing bacteria per cubic centimeter in raw and pasteurized ("flash" process) milk held at 10° C. (50° F.).*

| Sample No. | Kind of milk. | Temperature of pasteurization. | Days. | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1. | 2. | 3. | 4. | 5. | 6. |
| 5-6 | Raw | .......... | 500.000 | 4,700,000 | 10,000,000 | .......... | .......... | .......... |
| 5 | Pasteurized | 71.1° C. (160° F.) | 100,000 | 30,000 | 500,000 | 2,000,000 | .......... | .......... |
| 6 | do | 65.6° C. (150° F.) | .......... | 100,000 | 700,000 | 2,000,000 | .......... | .......... |
| 1 | Raw | .......... | 100,000 | 400,000 | 400,000 | 600,000 | 400.000 | 200,000 |
| | Pasteurized | 76.7° C. (170° F.) | 1,500 | 9,000 | 7,000 | 400,000 | 1,600,000 | 13,000,000 |
| 2 | Raw | .......... | 32,000 | 360,000 | 1,500,000 | 4,000.000 | 3,600,000 | .......... |
| | Pasteurized | 79.4° C. (175° F.) | 1,100 | 2,000 | 3,000 | 10,000 | 150,000 | .......... |
| 3 | Raw | .......... | 30,000 | 1,000,000 | 7,900,000 | 2,000,000 | .......... | .......... |
| | Pasteurized | 82.2° C. (180° F.) | 1,000 | 20,000 | 170,000 | .......... | .......... | .......... |
| 4 | Raw | .......... | 2,700,000 | 1,000,000 | 200,000 | 10,000,000 | .......... | .......... |
| | Pasteurized | 85° C. (185° F.) | 5,000 | 30,000 | 1,000,000 | 3,000,000 | .......... | .......... |
| 7-11 | Raw | .......... | 2,600,000 | 400,000 | 1,000,000 | .......... | .......... | .......... |
| 7 | Pasteurized | 60° C. (140° F.) | 100 | 44,000 | .......... | 100,000 | 500,000 | 1,000,000 |
| 8 | do | 65.6° C. (150° F.) | 500 | 280,000 | 100,000 | .......... | 700,000 | 2,000,000 |
| 9 | do | 71.1° C. (160° F.) | 500 | .......... | 30,000 | 100,000 | 1,200,000 | 2,000,000 |
| 10 | do | 76.7° C. (170° F.) | 1,100 | .......... | .......... | 200,000 | 800,000 | 2,000,000 |
| 11 | do | 82.2° C. (180° F.) | 6,000 | 10,000 | 50,000 | 400,000 | 1,100,000 | 7,000,000 |
| 12-16 | Raw | .......... | .......... | 100,000 | 100,000 | .......... | .......... | .......... |
| 12 | Pasteurized | 60° C. (140° F.) | 100 | 400 | 900 | 30.000 | 700,000 | 1,000,000 |
| 13 | do | 65.6° C. (150° F.) | .......... | 100 | 1,000 | 9.000 | 300,000 | 1,000,000 |
| 14 | do | 71.1° C. (160° F.) | .......... | 100 | 1,000 | 10.000 | 140,000 | 1,500,000 |
| 15 | do | 76.7° C. (170° F.) | .......... | 100 | 100 | 3,000 | 100,000 | 600,000 |
| 16 | do | 82.2° C. (180° F.) | 900 | 400 | 3,000 | 30,000 | 1,100,000 | 3,000,000 |

### EXPERIMENTS WITH MILK HELD AT ROOM TEMPERATURE.

Table 3 shows the results of two experiments in which the pasteurized milk was held at room temperature. The temperature ranged from 22° to 25° C. (71.6° to 77° F.) during the experiments.

In the first series—samples 17 to 21—the raw milk remained sweet until the second day. The pasteurized milks all soured with normal acid curds on the third day. In the second series—samples 22 to 26—where the counts were all higher, both the raw and the pasteurized milk soured in twenty-four hours with solid curds and a little gas.

TABLE 3.—*Comparison of raw and pasteurized ("flash" process) milk held at 22-25° C. (71.6-77° F.).*

| Sample No. | Kind of milk. | Temperature of pasteurization. | First day. | | | | Second day. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Acidity. | | Total bacteria per c. c. | Peptonizing bacteria per c. c. | Acidity. | Total bacteria per c. c. | Peptonizing bacteria per c. c. |
| 17-21 | Raw...... | ............... | 0.20 | | 1,030,000 | 250,000 | 0.84 | ............... | ......... |
| 17 | Pasteurized. | 60° C.(140° F.). | .17 | | 10,000 | 8,000 | .22 | 46,600,000 | 10,500,000 |
| 18 | .....do...... | 65.6° C. (150° F.). | .18 | | 300 | 100 | .18 | 13,000,000 | 1,100,000 |
| 19 | .....do...... | 71.1° C. (160° F.). | .18 | | 300 | ......... | .19 | 14,000,000 | 1,600,000 |
| 20 | .....do...... | 76.7° C. (170° F.). | .17 | | [a] | ......... | .18 | 7,140,000 | 1,100,000 |
| 21 | .....do...... | 82.2° C. (180° F.). | .15 | | 300 | 200 | .17 | 9,860,000 | 1,200,000 |
| | | | 9 a.m. | 3 p.m. | | | | | |
| 22-26 | Raw...... | ............... | 0.19 | 0.43 | 63,250,000 | [b] | .92 | 650,000,000 | [b] |
| 22 | Pasteurized. | 60° C.(140° F.). | .15 | .18 | 385,300 | | .72 | 435,000,000 | |
| 23 | .....do...... | 65.6° C. (150° F.). | .16 | .17 | 127,800 | | .78 | 386,000,000 | |
| 24 | .....do...... | 71.1° C. (160° F.). | .16 | .18 | 38,500 | | .80 | 100,000,000 | |
| 25 | .....do...... | 76.7° C. (170° F.). | .17 | .17 | 31,800 | | .75 | 558,000,000 | |
| 26 | .....do...... | 82.2° C. (180° F.). | .15 | .15 | 419,700 | | .79 | 1,132,000,000 | |

| Sample No. | Kind of milk. | Temperature of pasteurization. | Third day. | | | Remarks. |
|---|---|---|---|---|---|---|
| | | | Acidity. | Total bacteria per c. c. | Peptonizing bacteria per c. c. | |
| 17-21 | Raw...... | ............... | ..... | ............... | ......... | Coagulated on second day. |
| 17 | Pasteurized. | 60° C. (140° F.). | 0.86 | 1,560,000,000 | ......... | Sour on third day; solid curd. |
| 18 | .....do...... | 65.6° C. (150° F.) | .83 | 1,450,000,000 | 1,000,000 | Do. |
| 19 | .....do...... | 71.1° C. (160° F.) | .63 | 1,050,000,000 | ......... | Coagulated and sour on third day. |
| 20 | .....do...... | 76.7° C. (170° F.) | .62 | 790,000,000 | 1,000,000 | Do. |
| 21 | .....do...... | 82.2° C. (180° F.) | .52 | 735,000,000 | ......... | Do. |
| 22-26 | Raw...... | ............... | ..... | ............... | ......... | Coagulated with gas third day. |
| 22 | Pasteurized. | 60° C. (140° F.). | ..... | ............... | ......... | Coagulated third day; slight amount of gas. |
| 23 | .....do...... | 65.6° C. (150° F.) | ..... | ............... | ......... | Do. |
| 24 | .....do...... | 71.1°C. (160° F.) | ..... | ............... | ......... | Do. |
| 25 | .....do...... | 76.7° C. (170° F.) | ..... | ............... | ......... | Do. |
| 26 | .....do...... | 82.2° C. (180° F.) | ..... | ............... | ......... | Do. |

[a] 0 in 100 dilutions.

[b] Gelatin plates lost.

### THE INCREASE IN ACIDITY.

The formation of acid is shown graphically in figure 1.

In this experiment two series of samples of raw and pasteurized milk were heated at different temperatures, one set being held at 10° C. (50° F.) and the other at room temperature, 22° to 28° C. (71.6° to 82.4° F.). Figure 1, *A*, shows the increase in acidity in the milk held at 10° C. (50° F.). It is seen that the acidity in the raw milk began to increase during the first twenty-four hours and continued rapidly, reaching 0.44 per cent on the third day. The pasteurized milk did not change in acidity until the fifth day in one sample and the sixth day in the other samples, but the acidity then increased. Of the pasteurized samples it will be seen that the acidity began to increase first in the milk pasteurized at 82.2° C. (180° F.), the highest temperature. This may be explained in the same way as were the higher counts in Table 1.

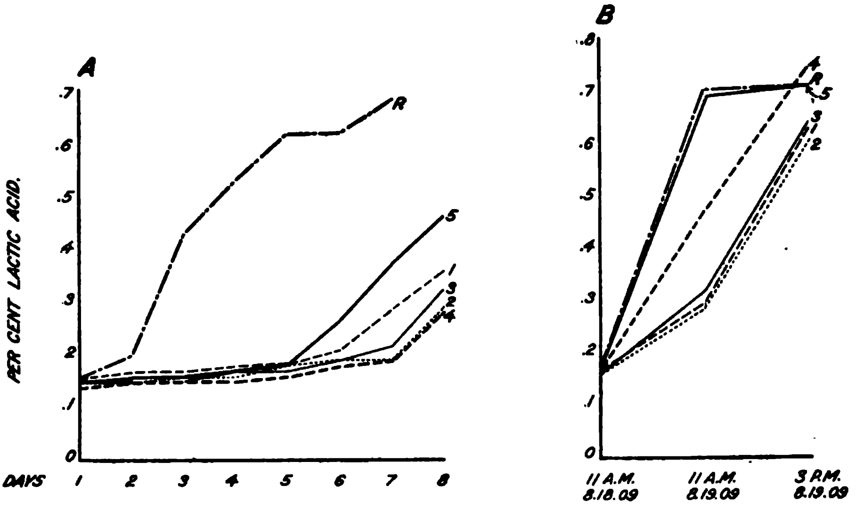


FIG. 1.—Pasteurization experiments. Comparison of acidity of pasteurized ("flash" process) and raw milk. *A*, milk held at 10° C. (50° F.); *B*, milk held at room temperature 22° to 28° C. (71.6° to 82.4° F.). Samples for both series collected from pasteurizer at same time. *R*, raw milk; *1*, milk pasteurized at 60° C. (140° F.); *2*, milk pasteurized at 65.6° C. (150° F.); *3*, milk pasteurized at 71.1° C. (160° F.); *4*, milk pasteurized at 76.7 C. (170° F.); *5*, milk pasteurized at 82.2° C. (180° F.).

The acidity in the other series of samples, held at room temperature, is shown in figure 1, *B*. The raw milk and the milk pasteurized at 82.2° C. (180° F.) soured in twenty-four hours, having an acidity of approximately 0.7 per cent. The same explanation as before accounts for the acidity of the pasteurized sample. In the other samples the acidity began to increase at once, and at 3 o'clock on the second day the acidities were all above 0.60 per cent. The souring in the pasteurized milk held at 10° C. (50° F.) was delayed until the sixth day. In similar milk held at room temperature the souring was delayed only a few hours.

These experiments indicate that pasteurization does not prevent milk from souring, but merely delays the process.

### COMPARISON OF RAW MILK AND MILK PASTEURIZED BY THE "HOLDER" PROCESS.

A few experiments were made using the "holder" process for pasteurizing. The milk was heated in the same "flash" machine used in the preceding experiments, from which it flowed into a steamed-covered can, where it was held. The temperature of the milk dropped only 2 degrees (Centigrade) during the holding. The results are shown in Tables 4 and 5.

#### REDUCTION OF BACTERIA DURING THE HOLDING PROCESS.

Ten minutes were required to fill the holding can, and that time must be added to all the holding periods as shown in Table 4. It may be seen that twenty minutes' holding was almost as efficient as the forty minutes' holding as shown in the last column of the table.

Another experiment was carried out under the same conditions except that the milk was pasteurized in a jacketed can and held for varying lengths of time. The results are shown in Table 5. As in the previous experiment, twenty minutes' holding was nearly as efficient as forty minutes' holding. The two samples heated to 60° C. (140° F.) and held for forty minutes, also the two heated to 65.6° C. (150° F.), all curdled with an acid curd in forty-eight hours when held at room temperature. On the other hand, one of the two samples heated to 71.1° C. (160° F.) curdled with a rennet curd after twenty-four hours at room temperature, while the other curdled after forty-eight hours with an acidity of 0.41 per cent and was partly digested.

TABLE 4.—*Showing reduction of bacteria per cubic centimeter during pasteurization by the "holder" process.*

| Bacteria in raw milk. | Pasteurizing temperature. | Sample taken directly from pasteurizer. | Sample taken when holding can was full. | After holding in can— | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 5 minutes. | 10 minutes. | 15 minutes. | 20 minutes. | 25 minutes. | 30 minutes. |
| 5,850,000 | 60° C. (140° F.) | .......... | 1,189,000 | 239,000 | 117,000 | 57,000 | 192,000 | 153,000 | 46,900 |
| 24,900,000 | 65.6° C. (150° F.) | .......... | 768,000 | 481,000 | 129,000 | ........ | 127,000 | 39,800 | 45,000 |
| 3,200,000 | 71.1° C. (160° F.) | 4,200 | .......... | .......... | 4,200 | ........ | 2,100 | 3,000 | 1,600 |
| 35,000,000 | 76.7° C. (170° F.) | .......... | 3,450 | 200 | 500 | (a) | 200 | 200 | 80 |

[a] 0 in 100 dilutions.

TABLE 5.—*Showing reduction of bacteria per cubic centimeter by heating and holding milk in the same can.*

| Sample No. | Bacteria in raw milk. | Pasteurizing temperature. | Sample taken when temperature reached pasteurizing temperature. | After holding in can— | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 5 minutes. | 10 minutes. | 15 minutes. | 20 minutes. | 25 minutes. | 30 minutes. | Remarks. |
| 1 | 21,000,000 | 60° C. (140° F.) | 4,032,000 | 3.743.000 | 2,394,000 | 514,000 | 1,386,000 | 320,000 | 1,071,000 | Curdled after 48 hours at room temperature; 81 per cent acid; sour, smooth curd. |
| 2 | 3,150,000 | .....do | 337,000 | 47,000 | 28,000 | 24,000 | 50,000 | 33,000 | 32,000 | Curdled, 48 hours; 0.42 per cent acid; smooth curd. |
| 3 | 19,400,000 | 65.6° C. (150° F.) | 596,000 | 70,000 | 18.000 | 2,000 | 5,750 | 5,100 | 12,000 | Curdled, 48 hours; 0.52 per cent acid. |
| 4 | 4,340,000 | .....do | 185,000 | 63,000 | 62,000 | 14,600 | 14,000 | 26,900 | ............ | Curdled, 48 hours at 30° C.; 64 per cent acid. |
| 5 | 536,000 | 71.1° C. (160° F.) | 41,000 | 9,000 | 100 | 100 | 200 | 100 | 100 | Curdled after 24 hours at room temperature; sweet rennet curd; acidity 0.17 per cent. |
| 6 | 70,000,000 | .....do | 120,000 | 1,430 | 3,020 | 460 | 250 | 640 | 770 | Curdled, 48 hours; acidity 0.41 per cent; partly digested. |

These experiments show that a high temperature for a considerable period is required to prevent souring. It is evident, too, that peptonizing bacteria are of no more importance than in raw milk, for the milk must be held four or five days before their numbers in pasteurized milk are as great as those in raw milk. The results also indicate that milk always sours when pasteurized under conditions that would prevail in commercial work, although the souring is delayed.

## EXAMINATION OF PASTEURIZED AND RAW MILK UNDER COMMERCIAL CONDITIONS.

The experiments which have been described indicated what might be expected of commercially pasteurized milk in general and suggested the procedure for the following work.

### THE PASTEURIZED MILK SUPPLY OF A SMALL CITY.

An examination was first made of pasteurized milk in a small community, as it was thought that the conditions in a small city might differ from those of the larger ones.

The pasteurized milk used in this case was obtained from a plant that had been in operation about three weeks. Before pasteurizing, the milk was run through a separator from which both the skim milk and the cream flowed directly into a heater where it was pasteurized. Two bottles of milk were delivered daily to a private residence and then taken directly to the laboratory. Thus the work was carried on without the knowledge of the milk company, and in this way milk was obtained which exactly represented the city supply. When the milk was received at the laboratory it was well mixed and a portion poured off to facilitate the shaking, in order to get a representative bacteriological sample. One bottle was held at 10° C. (50° F.) and the other at 22° C. to 25° C. (71.6° to 77° F.). The data obtained are tabulated in Tables I and II in the appendix.

It may be advisable to give a word of explanation in regard to "0" days which is used in the tables. In this and later tables "0" days is taken as the day the milk was received at the laboratory; this does not mean that the milk was not a day old, but that it was the time the consumer would receive it. It is probable that in many cases this milk was twenty-four hours old, dating from the time of pasteurization. As may be seen from the tables, the bacteria were divided into three groups—peptonizing, lactic acid, and alkali or inert bacteria.

Under peptonizing bacteria were classed all forms which liquefied gelatin. But it must be remembered that all bacteria which liquefy gelatin do not necessarily digest casein, nor do all casein peptonizers cause the liquefaction of gelatin; however, it is safe to assume that the majority of bacteria that digest casein appear on the gelatin plate as liquefiers.

All bacteria that gave red colonies with litmus were classed under the head of lactic-acid bacteria. On account of the scope of this definition a number of gas formers were probably included and in the tables this has been indicated by adding "lactis aerogenes" or the letters L A. after the count.

In the group called alkali-formers or inert bacteria were classed all those forms which do not noticeably produce acid or liquefy gelatin. In some cases the organisms produced enough alkali to form distinct bluish colonies, but usually there were very few which were active enough to show any alkaline reaction and for this reason the alkali and inert bacteria were classed under one head. In many instances slow acid-producing organisms may not have produced red colonies on the gelatin plates and so would be classed under the group of alkali or inert bacteria. The percentages of the different groups together with the total counts are tabulated in Tables III and IV of the appendix. In these tables the total counts were on litmus lactose gelatin and the percentages are in terms of the bacterial count. The differential count was also made on litmus lactose gelatin plates.

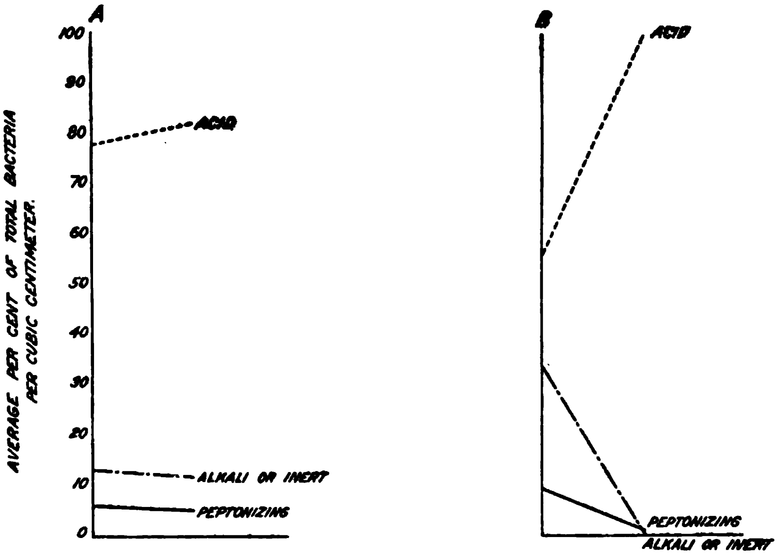


FIG. 2.—Pasteurized milk in a small city. Average daily counts and group percentages of bacteria and average daily acidity in *A*, milk held at 10° C. (50° F.), and *B*, milk held at room temperature, 22° to 25° C. (71.6° to 77° F.).

The percentages, total counts, and daily acidity have been averaged and are shown in Table 6 below, and in order to show the relation of the groups more plainly these results are given in graphic form in figure 2.

TABLE 6.—*Pasteurized milk in a small city—Average counts and group percentages of bacteria and acidity, compiled from data in Tables I, II, III, and IV of the appendix.*

| Acidity and bacteria. | Milk held at 10° C. (50° F.). | | Milk held at 22° C. to 25° C. (71.6–77° F.). | |
|---|---|---|---|---|
| | 0 days. | 1 day. | 0 days. | 1 day. |
| Acidity, in percentage of lactic acid | 0.15 | 0.17 | 0.16 | 0.64 |
| Bacteria per cubic centimeter...number | 6,170,000 | 44,000,000 | 8,250,000 | 1,380,000,000 |
| Peptonizing bacteria...per cent | 6.72 | 5.18 | 9.92 | 1.14 |
| Lactic-acid bacteria...do | 78.71 | 82.79 | 56.76 | 99.03 |
| Alkali or inert bacteria...do | 13.39 | 12.00 | 33.97 | .19 |

While it may be seen that sometimes the group percentages of the individual samples did not exactly follow the average percentages, it is believed that the average figures show the true relation from day to day.

Unfortunately, in the first part of this work the milk was examined for two days only, and the curve is short for that reason. An examination of the curve of the milk held at 10° C. (50° F.) shows a high initial percentage of lactic-acid bacteria, which increased on the second day. The peptonizing and alkali or inert bacteria were low and the per cent of the total decreased on the second day. It must be understood that where the curve is a downward one it does not mean a decrease in actual numbers but simply a lower proportion of the total number. For example, take the peptonizing bacteria. On the first day these were approximately 6 per cent of 6,170,000 bacteria per cubic centimeter, while on the second day they were approximately 5 per cent of 44,000,000 per cubic centimeter. During that time there was a corresponding increase in the numbers and proportion of the lactic-acid bacteria.

The curve of the milk held at room temperature shows the same relative position of the three groups. At the time the consumer would receive it the average group proportion was: Peptonizers, 9.92 per cent; lactic-acid bacteria, 56.76 per cent; alkali and inert forms, 33.97 per cent. After holding twenty-four hours at room temperature the proportion of acid bacteria rapidly increased to 99.03 per cent, while the alkali or inert forms decreased to 0.19 per cent and the peptonizers to 1.14 per cent. The average acidity was 0.64 per cent, indicating a sour milk.

The result of the examination of this commercially pasteurized milk shows that the lactic-acid bacteria were not destroyed during pasteurization and that the souring at room temperature produced normal acid curds.

## A STUDY OF PASTEURIZED AND RAW MILK IN BOSTON.

For a study of pasteurized and raw milk in large cities, Boston, Mass., was first chosen. Milk from various sources was examined during the winter of 1908–9 and also during the month of June, 1909. The complete data obtained are tabulated in Tables V to X of the appendix.

The samples of milk in every case were delivered at private residences or bought at stores, so that they represent actual commercial conditions. In other words, the milk in every case represented the condition of market milk when received by the consumer. The "0" days count shows the condition of the milk when delivered. Milk purchased in stores—"loose" or "dipped" milk—was collected in clean milk bottles, as would be used by the average housewife. Differential counts were made on litmus lactose gelatin as in the previous work. The bacteria were divided into three groups as in the former case, and the percentages of each in every sample is shown in Table VIII of the appendix. The figures have been averaged, together with the total bacteria and acidity, and are tabulated in Table 7 below. As in the previous work, these averages are shown graphically in figure 3.

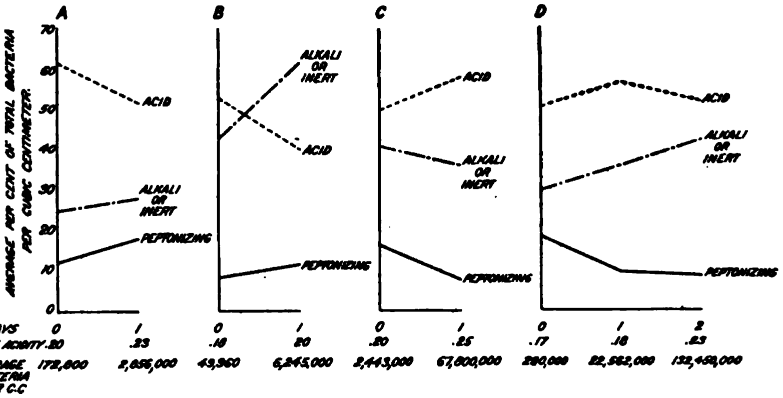


FIG. 3.—Pasteurized and raw milk in Boston, Mass., examined during November and December, 1908, and January, 1909. Average daily counts and group percentages of bacteria and average daily acidity in pasteurized and raw milk held at 10° C. (50° F.). *A*, pasteurized milk from dairy B, "flash" process, 60° to 65.6° C. (140° to 150° F.); *B*, pasteurized milk from dairy A, "holder" process, 60° to 65.6° C. (140° to 150° F.); *C*, pasteurized milk from dairy C, "flash" process, 71.1° to 73.8° C. (160° to 165° F.); *D*, raw milk from dairy G.

TABLE 7.—*Raw and pasteurized milk at Boston, Mass.—Average counts and group percentages of bacteria and acidity, compiled from data in Tables V and VIII of the appendix—Milk held at 10° C. (50° F.).*

| Acidity and bacteria. | Dairy A, pasteurized. | | Dairy B, pasteurized. | |
|---|---|---|---|---|
| | 0 days. | 1 day. | 0 days. | 1 day. |
| Acidity, in percentage of lactic acid | 0.18 | 0.20 | 0.20 | 0.23 |
| Bacteria per c. c. . . . Number | 49,960 | [a] 6,245,000 | 172,800 | 2,856,000 |
| Peptonizing bacteria . . . Per cent | 8.80 | 11.90 | 12.18 | 18.58 |
| Lactic-acid bacteria . . . do | 53.35 | 40.88 | 62.50 | 52.76 |
| Alkali or inert bacteria . . . do | 43.45 | 62.36 | 25.31 | 28.65 |

| Acidity and bacteria. | Dairy C, pasteurized. | | Dairy G, raw. | | |
|---|---|---|---|---|---|
| | 0 days. | 1 day. | 0 days. | 1 day. | 2 days. |
| Acidity, in percentage of lactic acid | 0.20 | 0.25 | 0.17 | 0.18 | 0.23 |
| Bacteria per c. c. . . . Number | 2,443,000 | 67,800,000 | 280,000 | 22,562,000 | 132,450,000 |
| Peptonizing bacteria . . . Per cent | 16.06 | 7.87 | 18.63 | 9.31 | 8.44 |
| Lactic-acid bacteria . . . do | 50.36 | 58.20 | 51.84 | 57.83 | 52.23 |
| Alkali or inert bacteria . . . do | 41.24 | 36.81 | 30.12 | 36.25 | 42.41 |

[a] High average due to one high count.

At this time it was not thought necessary to examine the milk after the second day, since milk in the home is usually consumed during the first twenty-four hours. Later, however, the advantage of a longer holding was noted, so that raw milk from dairy G was held for forty-eight hours. Figure 3 shows the curves of the milk held at 10° C. (50° F.).

Milk from dairy B was pasteurized by the "flash" process and from dairy A by the "holder" process. In both cases the milk was delivered in bottles. At dairy C the "flash" process was used and the pasteurized milk sold from cans in stores. Raw milk from dairy G was inspected milk of higher quality than ordinary market milk. By inspected milk is meant milk which is constantly being examined by a bacteriologist and produced from herds which are under the supervision of a veterinarian.

### WINTER MILK.

A comparison of the curves of dairy A and dairy B shows that the peptonizing bacteria were present in the smallest proportion in all cases. The best pasteurized milk was from dairy A, as shown by the count, and the curve shows a higher proportion of alkali or inert forms than does the milk from dairy B, also the percentages of lactic-acid bacteria were lower in dairy A. On the second day the percentage of alkali or inert bacteria had increased in the milk from dairy A so that they were present in greater proportion than the lactic-acid bacteria.

The curve of dairy B shows a decrease in the percentage of lactic-acid bacteria and an increase in the alkali or inert forms, but the original ratio still held. If the curves of dairies A and B are compared with the curve of dairy C, the milk from which showed a very high average count, it will be seen that the ratios were approximately the same on the first day, but changed on the second day. The proportion of acid bacteria increased instead of decreasing, and the alkali or inert forms decreased instead of increasing. The peptonizing bacteria also decreased in percentage instead of increasing slightly as they did in the other pasteurized milk.

The curves of group percentages of the raw milk show about the same initial group proportion as the pasteurized milk. The percentage of the lactic-acid bacteria was approximately the same as in the pasteurized milk. On the second day there was an increase in the proportion of acid bacteria, which, however, decreased on the third day. The percentage of alkali or inert forms increased steadily during the first two days, while the proportion of peptonizers decreased.

It may be seen that the relation of the three groups of bacteria was about the same in the pasteurized and raw milk during the first twenty-four hours except in the case of dairy A, where at the end of twenty-four hours the largest proportion of the bacteria consisted of alkali or inert forms. But although the proportion was lower, the actual number of alkali or inert bacteria in the raw milk at the end of twenty-four hours was greater than the number in milk from dairy A.

In regard to the peptonizing bacteria in pasteurized milk from dairies A and B, their actual numbers as shown by the average percentages of total count during the first twenty-four hours were lower than in the raw milk from dairy G. The pasteurized milk sold in cans from dairy C, however, showed a higher number of peptonizing bacteria than was found in the raw milk, both in the initial count and after twenty-four hours.

A number of samples of milk from dairies A and B were held at room temperature and examined in the same manner as those held at 10° C. (50° F.). The percentages of the three groups of bacteria and the total count are shown in Table IX of the appendix. The average of the percentages, together with the average total count and average acidity, are shown in Table 8 below, and are graphically represented in figure 4.

TABLE 8.—*Pasteurized milk at Boston, Mass.—Average counts and group percentages of bacteria and acidity, compiled from data in Table IX of the appendix—Milk held at 21.1° C. (70° F.).*

| Acidity and bacteria. | Dairy A, pasteurized. | | Dairy B, pasteurized. | |
|---|---|---|---|---|
| | 0 days. | 1 day. | 0 days. | 1 day. |
| Acidity, in percentage of lactic acid | 0.20 | 0.26 | 0.22 | 0.34 |
| Bacteria per c. c. ........ number.. | 72,000 | 104,000.000 | 170.000 | 300,137,000 |
| Peptonizing bacteria ........ per cent.. | 5.43 | 12.44 | 10.79 | 3.69 |
| Lactic-acid bacteria ........ do.... | 61.99 | 59.74 | 65.01 | 76.74 |
| Alkali or inert bacteria ........ do.... | 37.21 | 27.80 | 24.20 | 21.99 |

The curves explain themselves and only a few words need be said regarding them. In the curve of milk from dairy B the lactic-acid bacteria formed 65.01 per cent of the total, and increased to 76.74 per cent in twenty-four hours. The acid bacteria in milk from dairy A constituted 61.99 per cent of the total bacteria and decreased to 59.74 per cent. The alkali or inert forms were lower in proportion in the curve of dairy B than in dairy A, although they decreased in both in twenty-four hours. The peptonizers represented the smallest group in both cases. It will be noticed that the average bacterial count of milk from dairy A was less than one-half that of dairy B, and that with the lower count the lactic-acid group curve is downward, while in the higher count the curve is upward.

In regard to the milk examined in Boston during the winter it may be said that pasteurized milk from dairies A and B was equally as good bacteriologically as raw milk from an inspected dairy. The bacterial numbers were lower during the first twenty-four hours in the pasteurized milk, and the relative proportions of the three groups of bacteria, namely, peptonizing, lactic acid, and alkali or inert bacteria, were approximately the same. On the other hand, pasteurized milk from dairy C, which was sold from cans in stores, was very high in bacteria although the same relative proportion of groups held as in the milk from other sources.

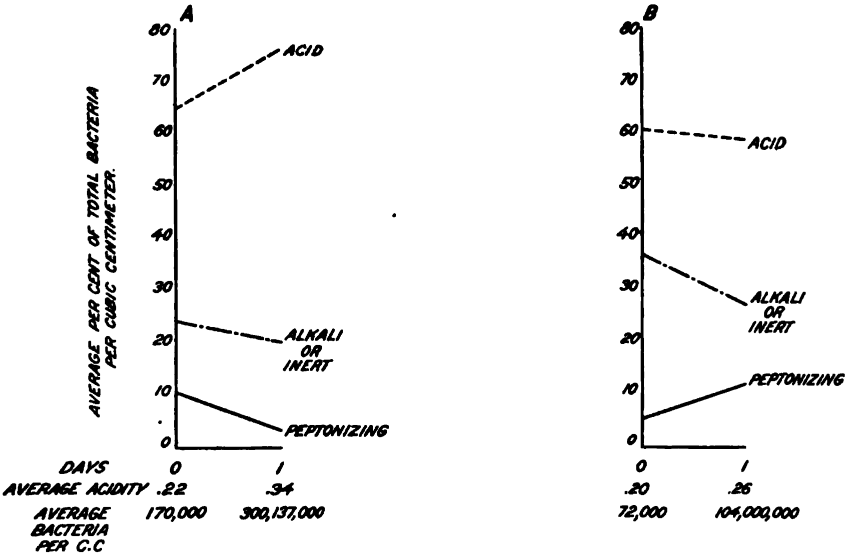


FIG. 4.—Pasteurized milk in Boston, Mass., examined during November and December, 1908, and January, 1909. Average daily counts and group percentages of bacteria and average daily acidity of pasteurized milk held at room temperature, 21.1° C. (70° F.). *A*, milk from dairy B, "flash" process, 60° to 65.6° C. (140° to 150° F.); *B*, milk from dairy A, "holder" process," 60° to 65.6° C. (140° to 150° F.).

### SUMMER MILK.

In order to study the condition of pasteurized milk in Boston in the summer, samples of milk from dairy A and raw milk from dairies E and F and from stores were examined during June, 1909. The same methods were employed as in the winter work. Table X in the appendix shows the total counts on litmus lactose gelatin and the percentages of the three groups of bacteria. All samples were held at 10° C. (50° F.). The averages are shown in Table 9 below, and also in figure 5.

TABLE 9.—*Raw and pasteurized milk at Boston, Mass., in summer—Average counts and group percentages of bacteria and acidity, compiled from data in Tables VII and X of the appendix—Milk held at 10° C. (50° F.).*

| Acidity and bacteria. | Dairies E and F and stores, raw. | | Dairy A, pasteurized. | | |
|---|---|---|---|---|---|
| | 0 days. | 1 day. | 0 days. | 1 day. | 2 days. |
| Acidity, in percentage of lactic acid | 0.17 | 0.24 | 0.15 | 0.15 | 0.19 |
| Bacteria per c. c. . . . number | 10,883,000 | 157,607,000 | 251,500 | 30,095,000 | 173,500,000 |
| Peptonizing bacteria . . . per cent | 8.71 | 6.59 | 14.71 | 12.16 | 9.19 |
| Lactic-acid bacteria . . . do | 57.00 | 62.17 | 22.00 | 31.56 | 71.04 |
| Alkali or inert bacteria . . . do | 36.21 | 35.18 | 66.81 | 64.28 | 25.30 |

It may be seen from the diagram that during the first twenty-four hours the three groups were not in the same relative proportion. In the pasteurized milk on the initial count 66.81 per cent of the total bacteria were alkali or inert forms, while in the raw milk the percentage was only 36.21 per cent. The curve of the alkali or inert forms is downward in both cases, and after forty-eight hours the relation of the alkali or inert forms to the acid group in the pasteurized milk was just reversed, the greater proportion of the total bacteria being lactic-acid forms. It is evident that in this series of samples a small proportion of lactic-acid bacteria was left, which soon increased so as to form the majority of the total bacteria. The curves of the peptonizing bacteria are downward in both cases. While the percentage was slightly higher in the pasteurized milk, it can be plainly seen from the average count that the actual number of peptonizers in the pasteurized milk was less than in the raw milk. The same thing

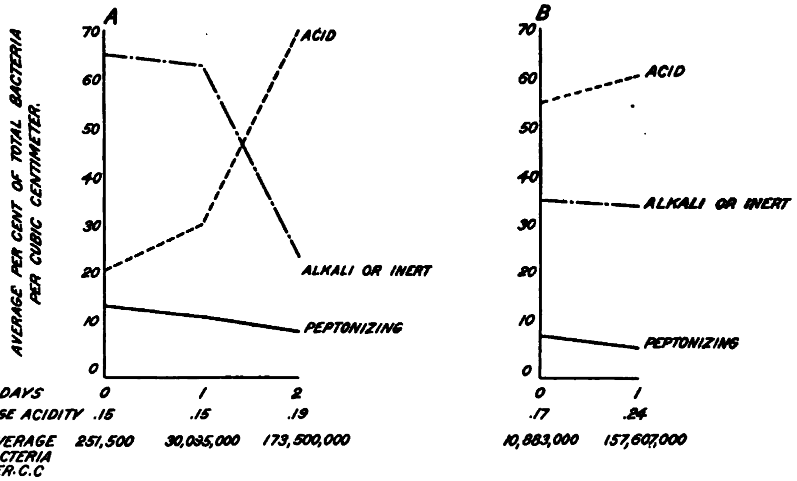


FIG. 5.—Pasteurized and raw milk in Boston, Mass., examined during June, 1909 Average daily counts and group percentages of bacteria and average daily acidity of pasteurized and raw milk held at 10° C. (50° F.). *A*, Pasteurized milk from dairy A, "holder" process, 60° to 65.6° C. (140° to 150° F.); *B*, Raw milk from stores and dairies E and F.

was true of the alkali or inert forms. Take, for example, the average initial count in the pasteurized milk, 251,000, of which 66.81 per cent were alkali or inert forms, which means approximately 168,000 per cubic centimeter. Compare that number with the initial count in the raw milk, which is 36.21 per cent of 10,883,000, or approximately 3,940,000. Even after twenty-four hours the same thing was true. The pasteurized milk had 64.28 per cent of 30,095,000, or approximately 19,345,000, as compared with 35.18 per cent of 157,607,000, or approximately 55,440,000, alkali or inert bacteria in the raw milk.

All of the bottles of pasteurized milk and most of the bottles of raw milk were delivered at a private residence at from 2 to 4 o'clock in the morning and were in many cases placed on the back fence, so that after sunrise they were directly in the sun's rays until taken into the house at 7 o'clock, which means that almost all the milk was exposed for several hours at a high temperautre, and explains the high bacterial count. Such methods of delivery, however, represented the average condition.

A few samples of raw and pasteurized milk were collected at the plant of dairy B. Unfortunately, during examination the gelatin plates from most of the samples melted, due to the very hot weather. The counts on litmus lactose agar and a few differential counts on gelatin, however, may be found in Table VII of the appendix. The samples of both raw and pasteurized milk were collected at the plant and taken to the laboratory without icing, and as the temperature was high, the high counts may be to some extent due to that fact. The raw milk represented the regular supply which was delivered to the consumer, while the pasteurized milk was practically the same milk heated. The samples were collected in steamed bottles just before and after pasteurization, then placed in the refrigerator of the dairy for twenty-four hours before examination, so as to duplicate commercial conditions. The total counts on lactose agar are shown below:

| Raw. | Pasteurized. |
|---|---|
| 14,500,000 | 1,760.000 |
| 25,000.000 | 1,450.000 |
| 8,900,000 | 6,300.000 |
| 48,000.000 | 1,210.000 |
| 12,600,000 | 215.000 |
| 32,000,000 | 16.900.000 |
|  | 4,095.000 |
|  | 1,940.000 |

From the differential counts in Table VII it will be seen that the group relation was about the same in the raw and the pasteurized milk. The milk was pasteurized by the "flash" process at a temperature of about 62.8° C. (145° F.). While the pasteurized milk was evidently better than the raw milk, the pasteurization was not efficient, due to the low temperature used. It may thus be seen that under summer conditions the pasteurized milk examined was equally good, if not better, from a bacteriological point of view than the raw milk.

### A STUDY OF PASTEURIZED AND RAW MILK IN NEW YORK CITY.

New York was chosen for the third representative city for the study of the pasteurized milk problem. The milk samples were delivered to or collected by private individuals so as to get representative market conditions. They were held at two temperatures, 10° C. (50° F.) and 20° C. (68° F.), and the differential bacteriological count was divided into three groups, all of which are represented in the data as shown in Tables XI and XII of the appendix. The total count in the milk held at 10° C. (50° F.) and the percentages of the differential groups on gelatin have been tabulated and shown in Table XIII. The average counts and group percentages of bacteria are given in Table 10 below, and these averages are graphically shown in figures 6, 7, and 8.

TABLE 10.—*Raw and pasteurized milk in New York City—Average counts and group percentages of bacteria and acidity, compiled from data in Tables XI and XIII of the appendix—Milk held at 10° C. (50° F.).*

DAIRY H, PASTEURIZED.

| Acidity and bacteria. | 0 days. | 1 day. | 2 days. | 3 days. | 4 days. | 5 days. | 6 days. |
|---|---|---|---|---|---|---|---|
| Acidity, in percentage of lactic acid | 0 19 | 0 19 | 0.20 | 0.20 | 0 27 | 0 33 | 0 53 |
| Bacteria per c. c. .number.. | 16,100 | 43,000 | 2,033,000 | 12,470,000 | 28,200,000 | 100,250,000 | 310,000,000 |
| Peptonizing bacteria, per cent | 3.71 | 17.53 | 16.05 | 11.35 | 4.74 | 5.58 | 2 29 |
| Lactic-acid bacteria, per cent | 30.26 | 6.79 | 24.18 | 39.06 | 28.60 | 51.68 | 77.32 |
| Alkali or inert bacteria, per cent | 62 32 | 78 31 | 69.51 | 57 91 | 66.76 | 41.82 | 20.87 |

DAIRIES K AND M, PASTEURIZED.

| Acidity and bacteria. | 0 days. | 1 day. | 2 days. | 3 days. |
|---|---|---|---|---|
| Acidity, in percentage of lactic acid | 0.19 | 0 19 | 0.20 | 0.25 |
| Bacteria per c. c. ....number.. | 21,400 | 558,000 | 5,317,000 | 72,600,000 |
| Peptonizing bacteria....per cent.. | 11.60 | 9.04 | 17.97 | 12.05 |
| Lactic-acid bacteria....do... | 29.56 | 41.83 | 26.67 | 45.84 |
| Alkali or inert bacteria....do... | 61.76 | 50.62 | 57.93 | 44.70 |

RAW.

| Acidity and bacteria. | 0 days. | 1 day. | 2 days. | 3 days. | 4 days. |
|---|---|---|---|---|---|
| Acidity, in percentage of lactic acid | 0.18 | 0.18 | 0 19 | 0.21 | 0.21 |
| Bacteria per c. c. ....number.. | 174,000 | 1,120,000 | 6,200,000 | 61,200,000 | 78,000,000 |
| Peptonizing bacteria....per cent.. | 14.92 | 15.85 | 37.34 | 20.81 | 20.94 |
| Lactic-acid bacteria....do... | 56.89 | 48.37 | 20.93 | 45.25 | 43.21 |
| Alkali or inert bacteria....do... | 29.27 | 36.65 | 46.00 | 34.08 | 39.67 |

Dairies H, K, and M represent three of the largest milk companies in New York which pasteurize their milk. The raw milk examined came from dairies P and N, which are two of the largest companies supplying raw milk. A few samples of raw milk were purchased in stores. The milk was held and examined for several days.

### THE DIFFERENTIAL BACTERIOLOGICAL CONTENT.

It may be seen from the diagrams that in the pasteurized milk the alkali or inert bacteria constituted the larger portion of the flora during the first few days, or until the acidity began to increase, at which time the percentage of lactic-acid bacteria took the lead. On the other hand, in the raw milk the lactic-acid forms were present in the greatest proportion on the initial count, but later on the other forms increased so that the lactic-acid bacteria were in the minority. They, however, later increased to a point where they again formed the largest group.

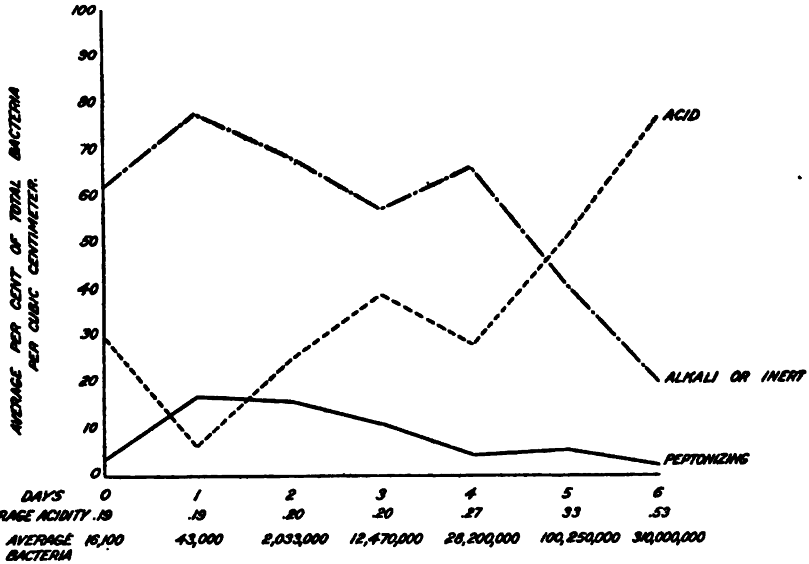


FIG. 6.—Pasteurized milk in New York City, "holder" process, examined during February and March, 1909. Average daily counts and group percentages of bacteria and average daily acidity in milk from dairy H, pasteurized at 60° to 65.6° C. (140° to 150° F.) and held for six days at 10° C. (50° F.).

A more careful analysis of each diagram shows numerous interesting points. Figure 6 shows the average counts, daily acidity, and group percentages of milk from dairy H. The milk was pasteurized by the "holder" process. One striking point was the low average counts even after twenty-four hours holding. The pasteurizing process was evidently very efficient, and this series of samples represents what can be done along the lines of pasteurization. Along with the low counts will be noticed a reversal of group ratios as compared with Boston; that is to say, a large proportion of alkali or inert bacteria was present rather than lactic-acid bacteria, as was the case in Boston with pasteurized milk of a higher initial count and also with raw milk. If the curves of the three groups are followed in figure 6 it will be seen that the proportion of alkali or inert forms increased slightly, then gradually decreased, until on the fifth day their percentage was lower than that of the lactic-acid bacteria. The latter, after a slight decrease in the first twenty-four hours, steadily increased until the sixth day, when they constituted 77.32 per cent of the total bacteria. The peptonizers were in the smallest proportion and increased slightly during the first twenty-four hours and then gradually decreased.

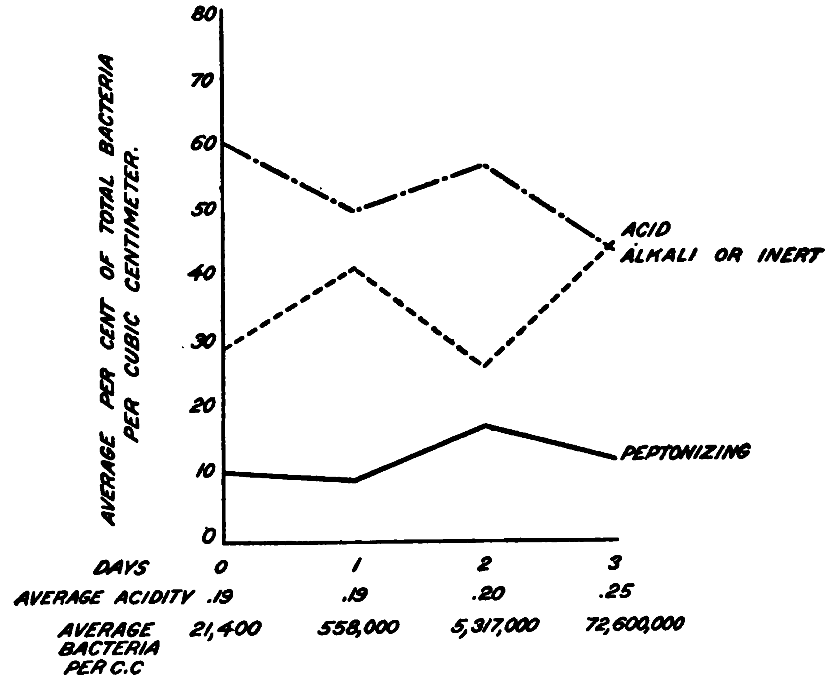


FIG. 7.—Pasteurized milk in New York City, "flash" process, examined during February and March, 1909. Average daily counts and group percentages of bacteria and average daily acidity in milk from dairies K and M, pasteurized at 70° to 71.1° C. (158° to 160° F.) and held for three days at 10° C. (50° F.).

Figure 7 shows the averages from milk pasteurized by the "flash" process. The curves of the groups are practically the same as those in figure 6. The alkali or inert forms were present in the greatest proportion and gradually decreased as the milk was held. The curve of the acid group is upward, while the peptonizers remained in relatively the same proportion. The variations in all these curves are due to the averaging in of some sample which had a very high count in some one group, so the curve of one group is raised and another one lowered. This point is shown in the curve in figure 7, where on the second day the alkali curve rises while the acid curve is correspondingly lowered.

Figure 8 shows the group percentages of raw milk held at 10° C. (50° F.). In the initial count there were 56.89 per cent of lactic-acid bacteria, as compared with 29.27 per cent of alkali or inert forms and 14.02 per cent of peptonizers. The curves show how the relative proportion held during four days. It is possible that the inverted ratio on the second day would not hold if more samples had been examined.

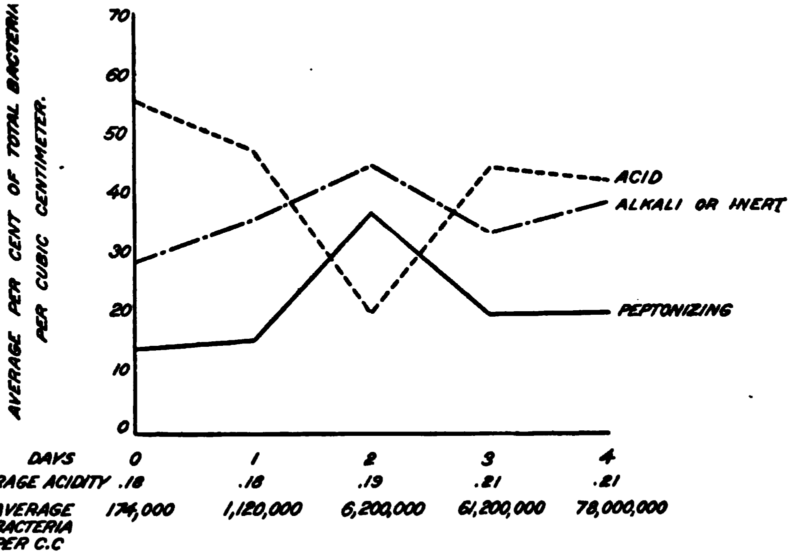


FIG. 8.—Raw milk in New York City, examined during February and March, 1909. Average daily counts and group percentages of bacteria and average daily acidity of milk held for four days at 10° C. (50° F.).

Other samples of milk from the same dairies were held at room temperature and examined in the same manner as those held at 10° C. (50° F.). Table XIV in the appendix shows the total counts and group percentages, and Table 11 below gives the average total counts, acidity, and group percentages. The averages are shown graphically in figure 9.

TABLE 11.—*Raw and pasteurized milk in New York City—Average counts and group percentages of bacteria and acidity, compiled from data in Tables XII and XIV of the appendix—Milk held at room temperature, 20° C. (68° F.).*

| Acidity and bacteria. | Dairy B, pasteurized. | | | Dairies K and M, pasteurized. | | Raw. | |
|---|---|---|---|---|---|---|---|
| | 0 days. | 1 day. | 2 days. | 0 days. | 1 day. | 0 days. | 1 day. |
| Acidity, in percentage of lactic acid | 0.20 | 0.20 | 0.53 | 0.17 | 0.22 | 0.18 | 0.28 |
| Bacteria per c. c., number | 12,300 | 6,006,000 | 317,000,000 | 13,000 | 20,900,000 | 129,000 | 84,000,000 |
| Peptonizing bacteria, per cent | 2.84 | 15.40 | 1.93 | 14.70 | 5.71 | 18.13 | 15.41 |
| Lactic-acid bacteria, per cent | 23.27 | 19.55 | 72.91 | 27.60 | 50.89 | 47.18 | 47.89 |
| Alkali or inert bacteria, per cent | 73.85 | 64.90 | 25.14 | 64.52 | 48.94 | 34.67 | 38.61 |

Little need be said regarding the curves, as they explain themselves. In the pasteurized milk the percentage of lactic-acid bacteria was small on the initial count, but in the case of dairy H after forty-eight hours, and dairies K and M after twenty-four hours, the majority of the total bacteria were of the lactic-acid group. In the raw milk the lactic-acid forms constituted the largest proportion on the initial count and the relative proportion of the three groups did not change. The actual numbers of the alkali or inert bacteria and the peptonizers were much less in the pasteurized milk than in the raw milk. It will also be noticed that, as was the case with the pasteurized milk held at 10° C. (50° F.), the percentage of the lactic-acid group reached that of the alkali or inert group more quickly in milk pasteurized by the "flash" process. This is seen in the curves of the milk from dairies H, K, and M in figures 6, 7, and 9. This is probably due to the fact that the lactic forms which survive the "holder" process grow slower than those left by the "flash" process. That lactic-acid bacteria do survive pasteurization will be shown later. The statement is often made that pasteurized milk does not sour, but this work does not support such a view.

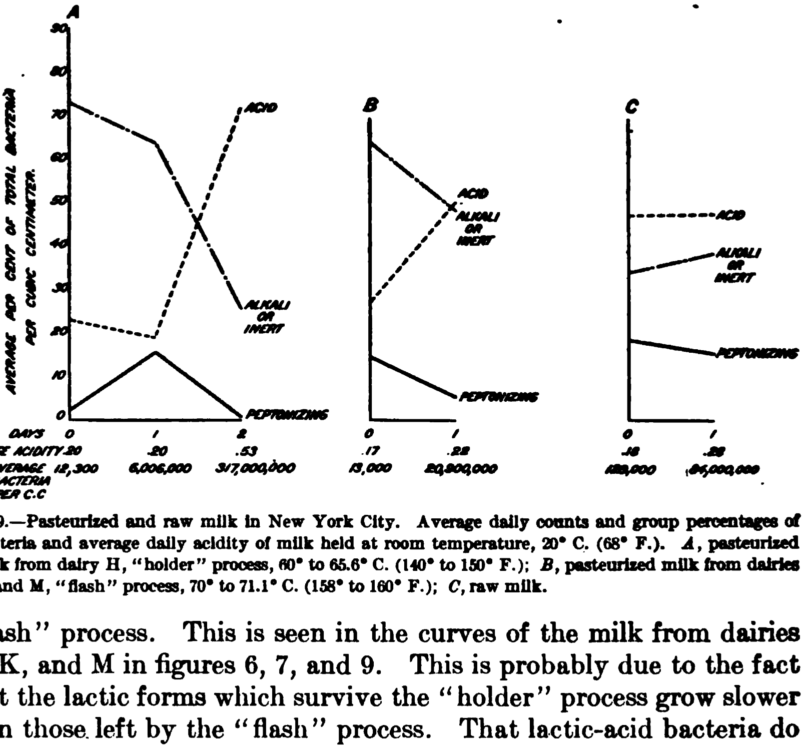


FIG. 9.—Pasteurized and raw milk in New York City. Average daily counts and group percentages of bacteria and average daily acidity of milk held at room temperature, 20° C. (68° F.). *A*, pasteurized milk from dairy H, "holder" process, 60° to 65.6° C. (140° to 150° F.); *B*, pasteurized milk from dairies K and M, "flash" process, 70° to 71.1° C. (158° to 160° F.); *C*, raw milk.

### DEVELOPMENT OF ACIDITY.

In figure 10 are given four curves, showing the acidity of various kinds of milk. Each curve, except the one for certified milk, represents the average daily acidity of a number of samples. The curve of acidity of certified milk represents one sample. All the samples of pasteurized and raw milk were low in bacteria initially and represented the best quality of milk of their respective kinds. In the samples held at 10° C. (50° F.) it may be seen that the pasteurized and raw milk soured at approximately the same time, while the certified remained sweet some few days longer. The same holds true in the acidity curves when the milk was held at room temperature. In the various tables of complete data in this paper will be found remarks as to the taste of milk after holding. Often a sample of milk has been marked as having an "old" taste which in many cases was so strong as to render the milk unfit for consumption. This taste is considered by many to be characteristic of pasteurized milk. This work has shown, however, that the "old" taste occurs in any milk, raw or pasteurized, which is low enough in bacteria to remain sweet for several days when held at low temperatures, and is probably due to the alkali or inert bacteria. The certified milk examined gave a putrid taste and odor on the seventh day, although not sour until the ninth or tenth day.

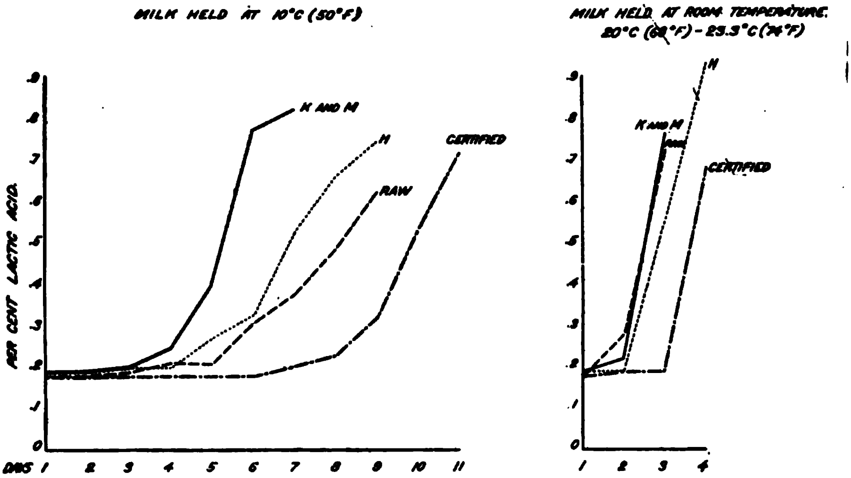


FIG. 10.—Pasteurized and raw milk in New York City. Comparison of average daily acidity at 10° C. (50° F.) and at room temperature, 20° to 23.3° C. (68° to 74° F.). *K and M*, milk pasteurized by "flash" process from dairies K and M; *H*, milk pasteurized by "holder" process from dairy H; *Raw*, raw milk from stores and dairies N and P; *Certified*, one sample of certified milk.

### GROWTH OF PEPTONIZING BACTERIA.

In Table 12 is tabulated the number of peptonizing bacteria in the pasteurized and raw milk in New York held at 10° C. (50° F.).

The table shows that the numbers of peptonizing bacteria in pasteurized milk were as low, if not lower, than in raw milk after twenty-four hours, and that they were much lower after forty-eight hours. Even when older the numbers of peptonizers were nearly equal in the two kinds of milk. If it is assumed that the peptonizing bacteria are not injurious in raw milk, then they can not be considered injurious in pasteurized milk, since their numbers in both kinds of milk are about the same.

**Table 12.**—*Raw and pasteurized milk in New York City—Comparison of growth of peptonizing bacteria—Milk held at 10° C. (50° F.).*

PASTEURIZED MILK.

"Holder" Process, 60° to 65° C. (140° to 150° F.).

| Sample No. | 0 days. | 1 day. | 2 days. | 3 days | 4 days. | 5 days. | 6 days. |
|---|---|---|---|---|---|---|---|
| 201 | 600 | 1,000 | 50,000 | 1,600,000 | .......... | 2,000,000 | .......... |
| 203 | (a) | .......... | 900,000 | .......... | 1,100,000 | .......... | 3,000,000 |
| 205 | 600 | 1,000 | .......... | 100,000 | .......... | 900,000 | 6,000.000 |
| 207 | 200 | .......... | 14,000 | .......... | 1,300,000 | 7,000,000 | 2,000,000 |
| 209 | .......... | 900 | .......... | 170,000 | 1,000,000 | 4,000,000 | 5,000,000 |
| 211 | 1,000 | .......... | 270,000 | 1,000,000 | 3,000,000 | 3,000,000 | .......... |
| 213 | 53,000 | (b) | 10,000 | 4,000,000 | 1,000,000 | .......... | .......... |
| 215 | 1,000 | 22,000 | 800,000 | 4,000,000 | .......... | .......... | .......... |
| 217 | 400 | 4,000 | 1,000,000 | 1,000,000 | .......... | .......... | .......... |
| 219 | 300 | 14,000 | 100,000 | .......... | .......... | .......... | .......... |
| 221 | 300 | 110,000 | .......... | .......... | .......... | .......... | .......... |

"Flash" Process, 71.1° C. (160° F.).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 225 | 1,000 | (c) | 300,000 | 4,000,000 | 4,000,000 | .......... | .......... |
| 227 | 1,300 | 10,000 | 700,000 | .......... | .......... | .......... | .......... |
| 229 | 800 | 6,000 | 3,000,000 | .......... | .......... | .......... | .......... |
| 231 | 500 | .......... | .......... | 1,000,000 | .......... | .......... | .......... |
| 233 | 800 | .......... | .......... | 1,100,000 | .......... | .......... | .......... |
| 235 | 1,400 | .......... | 100,000 | 600,000 | .......... | .......... | .......... |

PASTEURIZED IN COUNTRY.

"Flash" Process, 70° C. (158° F.).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 237 | 300 | 90,000 | 200,000 | .......... | .......... | .......... | .......... |
| 239 | 21,000 | 4,000.000 | 240,000 | 8,000,000 | .......... | .......... | .......... |
| 241 | 900 | 130,000 | .......... | 19,000,000 | .......... | .......... | .......... |
| 243 | 1,200 | 10,000 | 500,000 | 2,000,000 | .......... | .......... | .......... |
| 245 | 3,800 | .......... | (d) | 2,000,000 | .......... | .......... | .......... |

RAW MILK.

Bottled Milk.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 253 | 7,000 | 60,000 | 4,000,000 | .......... | 3,000,000 | .......... | .......... |
| 261 | 1,100 | (c) | 1,200,000 | 7,000,000 | 15,000,000 | .......... | .......... |
| 255 | 12,000 | 30,000 | 1,300,000 | 5,000,000 | .......... | 22,000,000 | .......... |
| 257 | 30,000 | 20,000 | 2,700,000 | .......... | 15,000,000 | 28,000,000 | .......... |
| 259 | 50,000 | 1,300,000 | .......... | 2,000,000 | 18,000,000 | .......... | .......... |

Different Milk from Stores.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 263 | 2,800,000 | 8,000,000 | 17,000,000 | 9,000.000 | .......... | .......... | .......... |
| 265 | 13,000 | 170,000 | 3,600,000 | 23,000.000 | 25,000,000 | 30,000 | .......... |
| 267 | 2,000 | 80.000 | 2,300,000 | 15,000,000 | .......... | .......... | .......... |
| 269 | 2,200 | 100,000 | 12,000,000 | .......... | .......... | .......... | .......... |

[a] 0 in 100 dilutions. [b] 0 in 1,000 dilutions. [c] 0 in 10,000 dilutions. [d] 0 in 100,000 dilutions.

### RAW MILK IN WASHINGTON, D. C.

After completing the investigation of pasteurized milk in Boston and New York it was thought advisable to obtain a good, clean, raw milk in order to show more conclusively the relation of the three bacterial groups. Two sources were drawn upon in Washington, D. C., and the results obtained are compiled in Tables XV and XVI of the appendix.

In order to make the entire investigation analogous, the same methods were employed with the exception of making no total count on lactose agar. The samples from dairy T were delivered at a private residence and then taken directly to the laboratory and plated. The samples from dairy S were bought on the open market. The samples were held at two temperatures, as before—10° C. (50° F.), and room temperature—and the bacterial counts divided into the same groups. In Table XVII the counts and percentages of the different groups are tabulated, and the averages in Table 13 below are drawn directly from these percentages. These averages are shown graphically in figure 11.

TABLE 13.—*Raw milk at Washington, D. C.—Average counts and group percentages and acidity, compiled from data in Table XVII of the appendix—Samples from dairy T milk held at 10° C. (50° F.).*

| Acidity and bacteria. | 0 days. | 1 day. | 2 days. | 3 days. | 4 days. | 5 days. | 6 days. |
|---|---|---|---|---|---|---|---|
| Acidity, in percentage of lactic acid | 0.16 | 0.17 | 0.18 | 0.27 | 0.42 | 0.56 | 0.66 |
| Bacteria per c. c., number | 186,000 | 8,200,000 | 54,500,000 | 236,000,000 | 352,000,000 | 557,000,000 | 519,000,000 |
| Peptonizing bacteria, per cent | 22.03 | 23.12 | 23.05 | 21.24 | 19.89 | 13.95 | 9.89 |
| Lactic-acid bacteria, per cent | 29.81 | 20.50 | 18.91 | 34.04 | 32.63 | 25.93 | 56.04 |
| Alkali or inert bacteria, per cent | 48.85 | 56.03 | 58.03 | 43.99 | 47.54 | 60.08 | 34.06 |

The milk described in Table 13 and figure 11 was held at 10° C. (50° F.), and represents a good grade. The average initial count is rather high, mostly due to one sample with an especially high count. In order to make the curve smooth the group percentages for the fifth day were not plotted. It may be seen that the curves correspond to those of the pasteurized milk in New York shown in figures 6 and 7; that is to say, the majority of the bacteria on the initial count were of the group of alkali or inert forms which gradually decreased. The lactic-acid group increased while the peptonizers decreased. If the curves are followed carefully it may be noted that the group of alkali or inert forms increased for two days, then decreased until the sixth day, when the lactic-acid bacteria were in the majority. The lactic forms decreased during the first forty-eight hours, then increased to 56.04 per cent of the total bacteria on the sixth day. The peptonizers were present initially in a larger percentage than is usual in the milk previously examined, but they gradually decreased. The acidity increased slowly, and if Table XV of the appendix is consulted it will be seen that on the third and later days many of the samples were described as having an "old" and in some cases a slightly putrid taste.

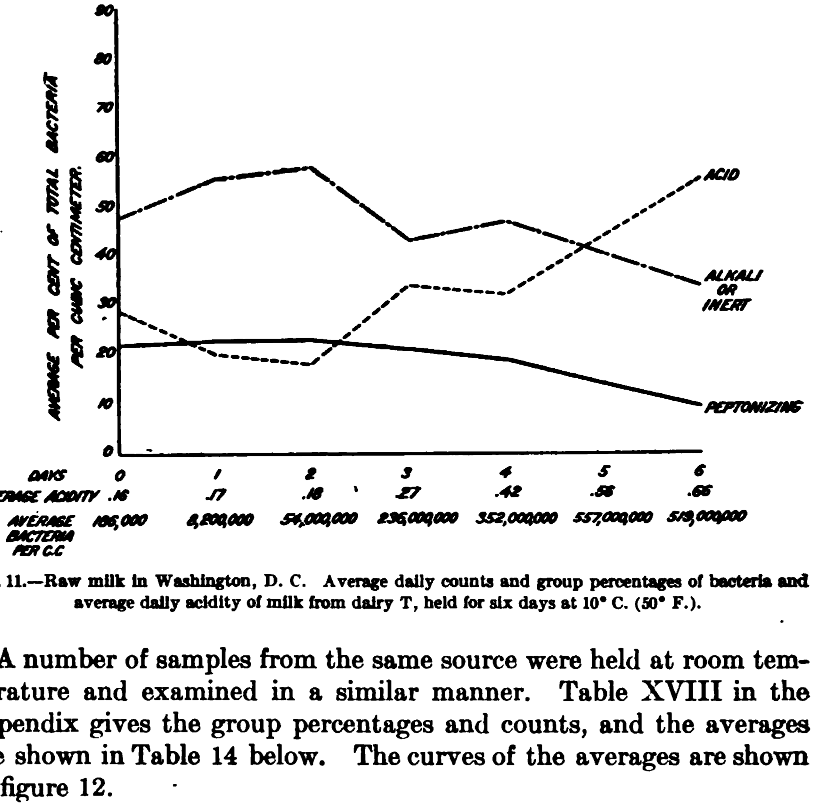


FIG. 11.—Raw milk in Washington, D. C. Average daily counts and group percentages of bacteria and average daily acidity of milk from dairy T, held for six days at 10° C. (50° F.).

A number of samples from the same source were held at room temperature and examined in a similar manner. Table XVIII in the appendix gives the group percentages and counts, and the averages are shown in Table 14 below. The curves of the averages are shown in figure 12.

TABLE 14.—*Raw milk at Washington, D. C.—Average counts and group percentages and acidity, compiled from data in Table XVIII of the appendix—Samples from dairy T—Milk held at room temperature, 20° C. (68° F.).*

| Acidity and bacteria. | 0 days. | 1 day. | 2 days. |
|---|---|---|---|
| Acidity, in percentage of lactic acid | 0.16 | 0.21 | 0.61 |
| Bacteria per c. c. ........number.. | 96,500 | 92,160,000 | 585,000,000 |
| Peptonizing bacteria........per cent.. | 14.67 | 24.17 | 10.15 |
| Lactic-acid bacteria........do.... | 35.38 | 27.78 | 54.50 |
| Alkali or inert bacteria........do.... | 50.68 | 48.03 | 35.95 |

The curves approximate very closely those of the pasteurized milk from dairy H, New York (see fig. 9). The percentage of the group of alkali or inert forms was closer to that of the lactic-acid group than in the case of the pasteurized milk, but they were in the majority, and so the relative proportion of the three groups was the same in both cases. As in the pasteurized milk from dairy H, the proportion held for twenty-four hours, after which the milk soured and the majority of the bacteria were in the lactic-acid group. The per cent of peptonizers increased during the first twenty-four hours and then decreased, but as in all previous samples constituted the minority group.

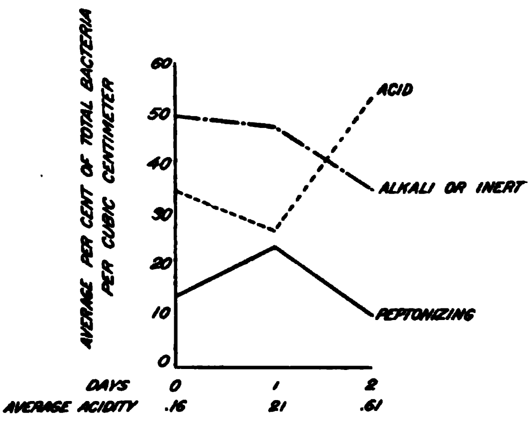


FIG. 12.—Raw milk in Washington, D. C. Average daily counts and group percentages of bacteria and average daily acidity of milk from dairy T, held for two days at room temperature, 20° C. (68° F.).

## DISCUSSION OF RESULTS OBTAINED FROM ANALYSIS OF COMMERCIAL MILK.

### A COMPARISON OF VARIOUS GRADES OF PASTEURIZED AND RAW MILK.

Since the bacterial flora of milk is believed to be changed after heating, it may be of interest to compare a few of the various grades of milk previously described. Figure 13 shows the group percentage curves of a good pasteurized milk as compared with a clean, raw milk held at 10° C. (50° F.).

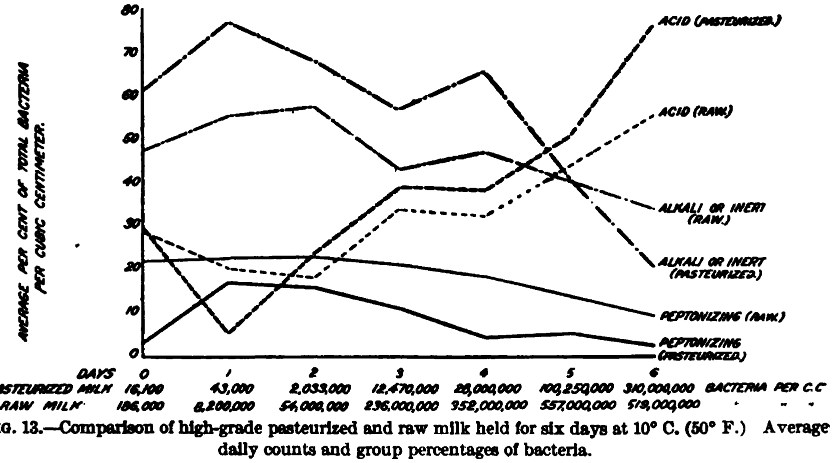


FIG. 13.—Comparison of high-grade pasteurized and raw milk held for six days at 10° C. (50° F.) Average daily counts and group percentages of bacteria.

In general it may be said that the relative proportion of the groups in a good grade of pasteurized milk is approximately the same as that in a clean, raw milk. The alkali or inert forms in both cases form the majority of the bacteria, and increase in their proportion during the first day and then gradually decrease until the fifth day, when their percentage is lower than that of the lactic-acid group. The acid bacteria constitute on the initial count from 20 to 30 per cent of the total, and after a decrease in proportion during the first twenty-four hours they gradually increase to form the largest portion of the bacterial content on the sixth day. In both the pasteurized and the raw milk the peptonizers are the smallest group; they increase slightly in proportion and then gradually decrease. The group percentages

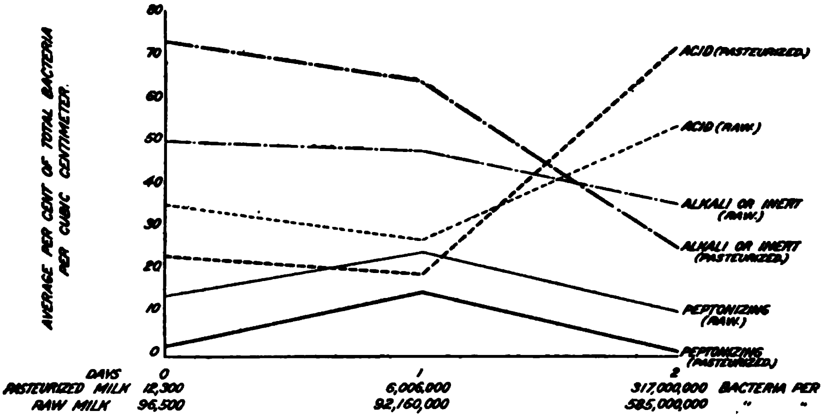


FIG. 14.—Comparison of high-grade pasteurized and raw milk held for two days at room temperature, 20° C. (68° F.). Average daily counts and group percentages of bacteria.

are much closer in clean, raw milk than in good, pasteurized milk, as may be seen from the diagram.

When the same grades are held at room temperature—20° C. (68° F.)—the group percentages stand in the same relative proportion in both the pasteurized and the raw milk (see fig. 14).

The groups stand in the same positions initially as in the series at 10° C. (50° F.), but their proportion in both cases changes after twenty-four hours. The change is the same as at the lower temperature, except that the lactic-acid group reach the ascendancy at the end of forty-eight hours instead of on the sixth day.

It is evident from these curves that, bacteriologically, a clean, raw milk is not superior to a good grade of pasteurized milk either in regard to the proportion of the various groups or to the actual bacterial numbers.

Having compared a good grade of pasteurized milk with a clean, raw milk, a good pasteurized milk may now be compared with an inspected milk of a little higher bacterial count than the clean milk and also with a less efficiently pasteurized milk.

In figure 15 *A* represents a clean, pasteurized milk, *B* a fair grade of inspected raw milk, and *C* an inferior grade of pasteurized milk. The most striking feature is the difference in percentages of the alkali or inert groups and the acid groups in the three kinds of milk. *B* and *C* are approximately alike, while in *A* the position of the acid and alkali or inert groups is inverted. That means that in less efficiently pasteurized milk less of the acid group are destroyed, so that after pasteurization the group percentages correspond closely to the proportion of the three groups in ordinary raw milk. On the other hand, in the best grades of pasteurized milk the acid bacteria are reduced so that the majority of bacteria are alkali or inert forms, as is the case in clean, raw milk. If *B* and *C* are compared it is hard to see how the raw milk can be called superior, bacteriologically, even to the less efficiently pasteurized milk.

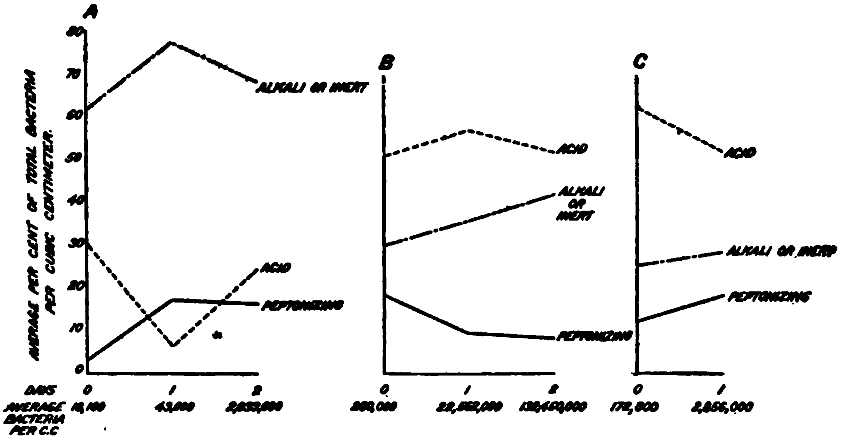


FIG. 15.—Comparison of high-grade and low-grade pasteurized milk with raw milk. Average daily counts and group percentages of bacteria in samples held at 10° C. (50° F.). *A*, good grade of pasteurized milk: *B*, fair grade of inspected raw milk; C, inferior grade of pasteurized milk.

## THE ABSENCE OF ACID BACTERIA IN BEST GRADES OF RAW MILK.

It has been shown in figure 13 that a clean, raw milk may have only a small percentage of lactic-acid bacteria, and this point may be more thoroughly shown in the following tables.

TABLE 15.—*Showing daily percentage of lactic acid and other bacteria in clean, raw milk.*

SAMPLE 251, CERTIFIED MILK HELD FOR SEVEN DAYS AT 10° C. (50° F.).

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c.c. on litmus lactose gelatin. | Peptonizing bacteria. | Lactic-acid bacteria. | Alkali or inert bacteria. |
|---|---|---|---|---|---|---|
| | | | *Number.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 251 | 0 | 0.18 | 300 | .......... | .......... | 100.00 |
| | 1 | .18 | .......... | .......... | .......... | .......... |
| | 2 | .18 | 2,000 | 50.00 | .......... | 50.00 |
| | 3 | .18 | 17,100,000 | 2.33 | .......... | 97.66 |
| | 4 | .18 | 15,000,000 | 20.00 | .......... | 80.00 |
| | 5 | .18 | 24,700,000 | 9.71 | .......... | 90.28 |
| | 6 | .......... | .......... | .......... | .......... | .......... |
| | 7 | .23 | 53,000,000 | 16.98 | 5.66 | 77.35 |

SAMPLE 252, CERTIFIED MILK HELD FOR THREE DAYS AT ROOM TEMPERATURE, 20° C. (68° F.).

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c.c. on litmus lactose gelatin. | Peptonizing bacteria. | Lactic-acid bacteria. | Alkali or inert bacteria. |
|---|---|---|---|---|---|---|
| 252 | 0 | 0.18 | 200 | .......... | .......... | 100.00 |
| | 1 | .19 | 10,000 | .......... | .......... | 100.00 |
| | 2 | .18 | 23,000,000 | 60.86 | 13.04 | 26.08 |
| | 3 | .69 | 481,000,000 | 2.91 | 65.90 | 31.18 |

Table 15 gives the total count, daily acidity, and group percentages in a sample of certified milk held at 10° C. (50° F.) and a duplicate sample at 20° C. (68° F.). In the milk held at the low temperature there was only a slight increase in acid during seven days. However, the bacterial content increased to 53,000,000 per cubic centimeter, of which only 5.66 per cent were of the lactic-acid group. Up to the seventh day no organisms of the acid group were found; the majority of the bacteria belonged to the group of alkali or inert forms, while on some days there was a considerable percentage of peptonizers. The fact that no lactic-acid bacteria were found on the plates during the first six days does not necessarily indicate that none were present, but merely shows that their numbers were so small that they did not show up at the dilutions made necessary by the numbers of the other groups. In the milk held at room temperature similar conditions existed during the first two days; that is to say, lactic-acid bacteria were absent, and in this special case peptonizers also. On the third day acid bacteria appeared and on the fourth day were in the majority.

The fact that the cleaner the milk the lower will be the percentage of lactic-acid bacteria is further supported by four samples of clean milk, three of which would come under the head of certified milk. The percentages of the various groups in these samples are shown in Table 16.

**Table 16.**—*Daily percentage of lactic acid and other bacteria in clean raw milk held at 10° C. (50° F.).*

| Sample No. | Age of milk in days. | Acidity as percentage of lactic acid. | Total bacteria per c. c. on litmus lactose gelatin. | Peptonizing bacteria. | Lactic-acid bacteria. | Alkali or inert bacteria. |
|---|---|---|---|---|---|---|
| | | | *Number.* | *Per cent.* | *Per cent.* | *Per cent.* |
| 341 | 0 | 0.19 | 4,400 | 34.09 | 13.63 | 52.27 |
| | 1 | .......... | 50,000 | 30.00 | .......... | 70.00 |
| | 2 | .21 | 31,200,000 | 9.61 | .......... | 90.38 |
| | 3 | .21 | 34,000,000 | 20.58 | .......... | 79.41 |
| | 4 | .20 | 200,000,000 | 30.00 | .......... | 70.00 |
| | 5 | .......... | 140,000,000 | 31.42 | .......... | 62.85 |
| | 6 | .28 | .......... | .......... | .......... | .......... |
| | 7 | .50 | 410,000,000 | 36.58 | 17.07 | 46.34 |
| 342 | 0 | .19 | 1,400 | 57.14 | 14.28 | 28.57 |
| | 1 | .20 | 4,000 | 52.50 | 22.50 | 25.00 |
| | 2 | .19 | 868,000 | 4.14 | .......... | 95.85 |
| | 3 | .......... | 36,700,000 | 8.71 | .......... | 91.28 |
| | 4 | .27 | 81,000,000 | 6.17 | .......... | 93.82 |
| | 5 | .......... | .......... | .......... | .......... | .......... |
| | 6 | .43 | 590,000,000 | 3.38 | 42.37 | 54.23 |
| 343 | 0 | .19 | 67,000 | 43.28 | 5.97 | 50.74 |
| | 1 | .......... | 8,200,000 | 20.73 | .......... | 79.26 |
| | 2 | .21 | 27,700,000 | 18.05 | .72 | 81.22 |
| | 3 | .......... | .......... | .......... | .......... | .......... |
| | 4 | .25 | 292,000,000 | 4.79 | 38.01 | 57.19 |
| 344 | 0 | .......... | 5,400 | 70.37 | 11.11 | 18.51 |
| | 1 | .21 | 170,000 | 35.29 | .......... | 64.70 |
| | 2 | .......... | .......... | .......... | .......... | .......... |
| | 3 | .24 | 122,000,000 | 11.47 | .81 | 87.70 |

A discussion of this table is hardly necessary. The absence of bacteria of the acid group may be noticed in all cases, also the correspondingly high percentage of the other two groups.

### THE BACTERIAL CONTENT OF PASTEURIZED AND RAW MILK.

Thus far the proportion of groups of bacteria in pasteurized and raw milk has been discussed. The bacterial numbers in both kinds of milk may now be considered.

#### INITIAL COUNTS OF BACTERIA.

In Table 17 the samples of pasteurized and raw milk are grouped into classes, the limits of which are purely arbitrary, based according to their counts. The bacterial numbers represent the initial count of bacteria per cubic centimeter in the various kinds of milk as the consumer received it. Comparison of pasteurized and raw milk in Boston shows that the bacterial numbers from dairies A and B were on the whole lower than those of raw milk from dairy G, although dairy G is one of the best dairies supplying raw milk to the city. The bacterial counts of the pasteurized milk from dairy C are given separately in order to show the high counts, which are quite significant.

This milk was sold from cans in markets and bakeries and very little was bottled except for special trade. The samples were purchased from shops at various times in glass milk bottles which were clean although not sterile. Undoubtedly, however, the conditions under which the milk was purchased duplicated those under which the housewife would purchase the same milk. An examination of the machine at the plant showed the process to be quite efficient, and doubtless the high counts were due to infection from the milk cans and wooden stoppers or to long holding of the milk in the shops. Whichever was the cause, it appears evident that pasteurized milk should not be supplied in cans, especially where it is to be sold to the consumer from stores. It may be seen from the table that in the summer pasteurized milk from dairy A was much lower in bacterial numbers than the raw milk examined. As explained earlier in this paper, in all the milk the counts were high, due to the method of delivery in which the milk was exposed to high temperatures during the early morning hours. The pasteurized milk examined in New York showed very low counts—29 out of a total of 39 being below 20,000 per cubic centimeter. The majority of the samples of pasteurized milk were much lower in bacteria than the raw milk.

TABLE 17.—*Comparison of bacterial content of raw and pasteurized milk from various sources—The samples of each kind of milk arranged in classes according to their initial bacterial count.*

| Class. | Bacteria per c. c. | Boston, winter. | | | Boston, summer. | | New York, winter. | |
|---|---|---|---|---|---|---|---|---|
| | | Pasteurized milk. | | Raw milk from dairy G. | Pasteurized milk from dairy A. | Raw milk from stores and dairies E and F. | Pasteurized milk from dairies H, K, and M. | Raw milk from dairies P and N and stores. |
| | | From dairies A and B. | From dairy C. | | | | | |
| | | *Samples.* | *Samples.* | *Samples.* | *Samples.* | *Samples.* | *Samples.* | *Samples.* |
| A | 0 to 20,000 | 7 | 1 | 1 | 3 | 0 | 29 | 0 |
| B | 20,000 to 50,000 | 16 | 1 | 2 | 3 | 0 | 5 | 3 |
| C | 50,000 to 100,000 | 8 | 1 | 4 | 0 | 0 | 3 | 2 |
| D | 100,000 to 500,000 | 15 | 0 | 12 | 5 | 0 | 2 | 10 |
| E | 500,000 to 1,000,000 | 1 | 0 | 3 | 1 | 0 | 0 | 1 |
| F | 1,000,000 to 10,000,000 | 0 | 17 | 2 | 0 | 13 | 0 | 1 |
| G | 10,000,000 to 50,000,000 | 2 | 2 | 0 | 0 | 5 | 0 | 1 |
| H | 50,000,000 or over | 0 | 1 | 2 | 1 | 3 | 0 | 0 |
| | Total number of samples | 49 | 23 | 26 | 13 | 21 | 39 | 18 |

### RATE OF INCREASE OF THE BACTERIA.

In a similar manner the various milks have been grouped according to their bacterial counts after holding twenty-four hours, the result of which is shown in Table 18. The pasteurized milk from dairies A and B in Boston was on the whole much lower than raw milk from dairy G. The same was true of pasteurized milk examined during the summer. The pasteurized milk from dairy C which was bought "loose" in stores showed a high count, corresponding, of course, to the initial high counts. In New York the pasteurized milk was strikingly low in bacteria even after twenty-four hours holding, which would be expected from the low initial counts. It is evident from these results that the pasteurized milk in both cities was of a very good quality. Of course this study did not include all the pasteurizing plants of the two cities, but it represents the three largest in each case.

TABLE 18.—*Comparison of rate of increase of bacteria in raw and pasteurized milk from various sources after holding for twenty-four hours at 10° C. (50° F.).*

| Class. | Bacteria per c. c. | Boston, winter. | | | Boston, summer. | | New York, winter. | |
|---|---|---|---|---|---|---|---|---|
| | | Pasteurized milk. | | Raw milk from dairy G. | Pasteurized milk from dairy A. | Raw milk from stores and dairies E and F. | Pasteurized milk from dairies H, K, and M. | Raw milk from dairies P and N and stores. |
| | | From dairies A and B. | From dairy C. | | | | | |
| | | *Samples.* | *Samples.* | *Samples.* | *Samples.* | *Samples.* | *Samples.* | *Samples.* |
| A | 0 to 20,000.............. | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| B | 20,000 to 50,000.......... | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| C | 50,000 to 100,000......... | 1 | 0 | 0 | 0 | 0 | 4 | 0 |
| D | 100,000 to 500,000........ | 7 | 0 | 1 | 1 | 0 | 4 | 2 |
| E | 500,000 to 1,000,000...... | 3 | 0 | 0 | 0 | 0 | 1 | 2 |
| F | 1,000,000 to 10,000,000... | 9 | 3 | 8 | 2 | 0 | 2 | 4 |
| G | 10,000,000 to 50,000,000.. | 1 | 5 | 7 | 7 | 1 | 0 | 0 |
| H | 50,000,000 or over........ | 1 | 8 | 6 | 1 | 16 | 0 | 1 |
| | Total number of samples........ | 22 | 16 | 22 | 11 | 17 | 17 | 9 |

The question of bacterial increase in pasteurized and raw milk is one which causes much discussion. The best authorities on the subject differ in their views, and any data that will tend to settle the question must necessarily be of value. The bacterial increase during the first twenty-four hours in a number of samples from the various sources used in this investigation has therefore been tabulated, the milk being held at 10° C. (50° F.). The details are given in Table 19, as follows:

TABLE 19.—*Ratio of increase of bacteria in pasteurized and raw milk after holding for twenty-four hours at 10° C. (50° F.).*

BOSTON, WINTER 1908-9—PASTEURIZED MILK FROM DAIRIES A AND B.

| Sample No. | Bacteria per c. c. | | Ratios. | Sample No. | Bacteria per c. c. | | Ratios. |
|---|---|---|---|---|---|---|---|
| | 0 days. | 1 day. | | | 0 days. | 1 day. | |
| 1 | 36,400 | 142,000 | 1:3.9 | 10 | 45,300 | 790,000 | 1:17.4 |
| 2 | 40,700 | 260,000 | 1:6.3 | 11 | 48,700 | 430,000 | 1:8.8 |
| 3 | 205,000 | 2,100,000 | 1:10.2 | 12 | 34,000 | 1,970,000 | 1:57.9 |
| 4 | 117,000 | 280,000 | 1:2.3 | 13 | 175,000 | 1,140,000 | 1:6.5 |
| 5 | 220,000 | 7,800,000 | 1:33.9 | 14 | 56,200 | 1,400,000 | 1:25.6 |
| 6 | 529,000 | 7,820,000 | 1:14.5 | 15 | 9,000 | 2,400,000 | 1:266.6 |
| 7 | 214,000 | 3,500,000 | 1:16.3 | 16 | 35,000 | 2,400,000 | 1:68.5 |
| 8 | 204,000 | 950,000 | 1:4.6 | | | | |
| 9 | 116,000 | 18,700,000 | 1:161.2 | Average ratio............ | | | 1:44.03 |

TABLE 19.—*Ratio of increase of bacteria in pasteurized and raw milk after holding for twenty-four hours at 10° C. (50° F.)*—Continued.

BOSTON, WINTER 1908-9—PASTEURIZED MILK FROM DAIRY C.

| Sample No. | Bacteria per c. c. |  | Ratios. | Sample No. | Bacteria per c. c. |  | Ratios. |
|---|---|---|---|---|---|---|---|
|  | 0 days. | 1 day. |  |  | 0 days. | 1 day. |  |
| 1 | 3,300,000 | 10,600,000 | 1:3.2 | 7 | 2,640,000 | 10,500,000 | 1:3.9 |
| 2 | 5,800,000 | 190,000,000 | 1:30.7 | 8 | 4,000,000 | 32,000,000 | 1:8.0 |
| 3 | 1,100,000 | 27,200,000 | 1:24.7 | 9 | 1,140,000 | 6,000,000 | 1:5.2 |
| 4 | 1,450,000 | 231,000,000 | 1:159.3 | 10 | 1,410,000 | 11,200,000 | 1:7.9 |
| 5 | 7,000,000 | 26,200,000 | 1:3.7 |  |  |  |  |
| 6 | 1,750,000 | 8,800,000 | 1:5.0 | Average ratio............ |  |  | 1:25.1 |

BOSTON, WINTER 1908-9—RAW MILK FROM DAIRY G.

|  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| 1 | 71,000 | 118,000 | 1:1.4 | 7 | 130,000 | 2,000,000 | 1:15.3 |
| 2 | 24,000 | 2,100,000 | 1:87.5 | 8 | 310,000 | 25,200,000 | 1:81.2 |
| 3 | 261,000 | 3,500,000 | 1:13.4 | 9 | 128,000 | 18,000,000 | 1:140.0 |
| 4 | 490,000 | 8,000,000 | 1:16.6 |  |  |  |  |
| 5 | 39,000 | 3,900,000 | 1:100.0 | Average ratio............ |  |  | 1:52.4 |
| 6 | 120,000 | 1,800,000 | 1:16.3 |  |  |  |  |

BOSTON, SUMMER 1909—PASTEURIZED MILK FROM DAIRY A.

|  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| 1 | 450,000 | 2,740,000 | 1:6.1 | 5 | 95,000 | 22,300,000 | 1:233.7 |
| 2 | 97,000 | 56,200,000 | 1:579.3 | 6 | 286,000 | 90,000,000 | 1:314.6 |
| 3 | 784,000 | 44,000,000 | 1:56.1 |  |  |  |  |
| 4 | 27,000 | 2,700,000 | 1:100.0 | Average ratio............ |  |  | 1:214.9 |

BOSTON, SUMMER 1909—RAW MILK FROM DAIRIES E AND F AND STORES.

|  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| 1 | 2,570,000 | 95,000,000 | 1:36.9 | 9 | 4,500,000 | 79,000,000 | 1:17.5 |
| 2 | 13,900,000 | 85,000,000 | 1:6.11 | 10 | 1,900,000 | 18,500,000 | 1:9.73 |
| 3 | 5,000,000 | 238,000,000 | 1:47.6 | 11 | 3,400,000 | 80,000,000 | 1:23.5 |
| 4 | 9,700,000 | 164,000,000 | 1:16.9 | 12 | 5,700,000 | 200,000,000 | 1:35.0 |
| 5 | 28,200,000 | 505,000,000 | 1:17.9 | 13 | 11,200,000 | 177,000,000 | 1:15.8 |
| 6 | 43,100,000 | 200,000,000 | 1:4.64 |  |  |  |  |
| 7 | 8,800,000 | 106,000,000 | 1:12.03 | Average ratio............ |  |  | 1:19.5 |
| 8 | 11,400,000 | 124,000,000 | 1:10.8 |  |  |  |  |

NEW YORK, WINTER 1909—PASTEURIZED MILK FROM DAIRY H.

|  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| 1 | 11,200 | 42,000 | 1:3.7 | 9 | 34,000 | 120,000 | 1:3.5 |
| 2 | 10,000 | 50,000 | 1:5.0 | 10 | 16,500 | 1,610,000 | 1:97.5 |
| 3 | 29,800 | 59,000 | 1:1.9 | 11 | 25,400 | 12,400,000 | 1:448.1 |
| 4 | 18,000 | 40,000 | 1:2.2 | 12 | 13,400 | 950,000 | 1:70.8 |
| 5 | 5,900 | 14,000 | 1:2.3 | 13 | 6,700 | 16,000 | 1:2.3 |
| 6 | 14,000 | 87,000 | 1:6.2 |  |  |  |  |
| 7 | 26,000 | 1,170,000 | 1:45.0 | Average ratio............ |  |  | 1:53.1 |
| 8 | 31,500 | 68,000 | 1:2.1 |  |  |  |  |

WASHINGTON, WINTER 1910—RAW MILK FROM DAIRY T.

|  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| 1 | 85,000 | 30,800,000 | 1:362.3 | 9 | 172,000 | 7,000,000 | 1:40.6 |
| 2 | 43,400 | 660,000 | 1:15.2 | 10 | 464,000 | 1,100,000 | 1:2.3 |
| 3 | 30,000 | 400,000 | 1:13.3 | 11 | 243,000 | 3,810,000 | 1:15.6 |
| 4 | 149,000 | 260,000 | 1:1.74 | 12 | 146,000 | 1,030,000 | 1:48.1 |
| 5 | 126,000 | 17,900,000 | 1:142.0 | 13 | 36,000 | 3,700,000 | 1:102.7 |
| 6 | 125,000 | 9,500,000 | 1:76.0 | 14 | 78,000 | 3,210,000 | 1:41.1 |
| 7 | 523,000 | 8,900,000 | 1:17.0 |  |  |  |  |
| 8 | 627,000 | 21,000,000 | 1:33.2 | Average ratio............ |  |  | 1:65.07 |

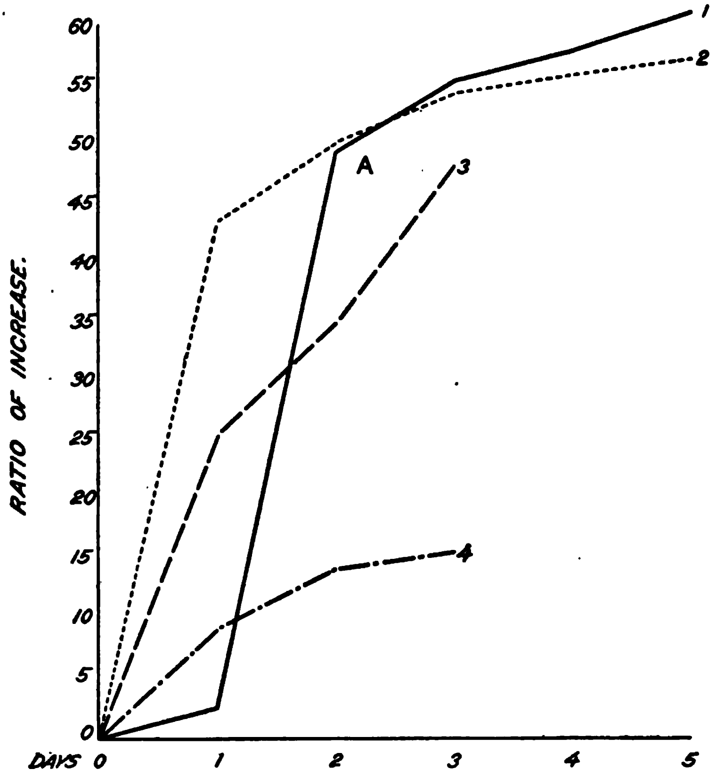
Taking first the Boston winter milk, the table shows the average ratio of bacterial increase in the series of pasteurized milk from dairies A and B to be 1 to 44.03; in raw milk from dairy G it is 1 to 52.40, and in pasteurized milk from dairy C it is 1 to 25.1. From these figures little difference is evident in the ratio of bacterial increase in pasteurized milk from dairies A and B and raw milk from dairy G. On the other hand, in pasteurized milk from dairy C the rate of increase was much lower. The question may be asked, Why not the same rate of increase in both series of pasteurized milk? The difference is easily explained if the first two sections of the table are compared. In the pasteurized milk from dairies A and B the initial counts of the samples were low as compared to those of dairy C. The ratio of increase in the first case was obtained during the rapid development of the bacterial numbers, while in the milk from dairy C the bacterial content was originally high, so that the period of active growth had passed and the initial counts were much nearer their ultimate point of increase. Rogers[18] has also suggested the fact that the period of rapid bacterial increase must be taken into consideration.

This point is shown more clearly in the fourth and fifth sections of the table, dealing with the Boston summer milk. It is here seen that in the pasteurized milk the average ratio is 1 to 214.9 as compared with 1 to 19.5 in the raw milk. Here again there were low initial numbers in the pasteurized milk and high ones in the raw milk. In this case it is true that the bacteria in the heated milk did increase faster than those in the raw milk, but it would not be correct to assume from these figures that bacteria increase faster in pasteurized milk in general. But suppose that the initial counts of the raw milk had been as low as the counts in the pasteurized milk, then the condition in both would be comparable, because in each case the ratios during the first twenty-four hours would cover the period of active increase. If under such conditions the same ratio of increase held as shown in the table, then it would be more reasonable to state that bacteria increase more rapidly in pasteurized than in raw milk.

This is well illustrated in the last two sections of the table. Here are shown the counts of the pasteurized milk from dairy H in New York and of the clean raw milk from dairy T in Washington. In both cases the initial counts were low and the ratios of bacterial increase were approximately the same. In both cases one or two twenty-four-hour high counts increased the average ratio, but on examination of the individual ratios it may be seen that in general the bacteria grew faster in the raw milk.

### INACCURACY OF RATIOS OF INCREASE WHEN INITIAL COUNTS VARY TOO WIDELY.

In order to show how misleading ratios may be, and how it is impossible to compare ratios of increase in samples of milk in which the initial counts vary widely, four kinds of milk have been chosen and their daily ratios of increase compared, as shown in Table 20 below and in figure 16. The four milks used consisted of the two pasteurized kinds—one by the "holder" and one by the "flash" process—a clean raw milk and a dirty raw milk. The ratios in the table represent the increase on each successive day and not from the first to second, first to third, etc. Curve 1 in figure 16 represents the milk pasteurized by the "holder" process, curve 2 the clean raw milk, curve 3 the milk pasteurized by the "flash" process, and curve 4 the dirty raw milk. In all cases the milk was held at 10° C. (50° F.). The curves have been plotted by using the actual ratios,



| AVERAGE BACTERIA PER C.C | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1 | 16,100 | 43,000 | 2,033,000 | 12,470,000 | 28,200,000 | 100,250,000 |
| 3 | 21,400 | 558,000 | 5,317,000 | 72,600,000 | | |
| 2 | 186,000 | 8,200,000 | 54,500,000 | 236,000,000 | 352,000,000 | 557,000,000 |
| 4 | 9,505,000 | 91,140,000 | 448,000,000 | 680,000,000 | | |

FIG. 16.—Comparison of the ratio of increase of bacteria in pasteurized and raw milk held for five days at 10° C. (50° F.). Average daily counts of bacteria and ratios of increase. *1*, pasteurized milk, "holder" process; *2*, clean raw milk; *3*, pasteurized milk, "flash" process; *4*, dirty raw milk.

the first point on the curve being the ratio of increase from the first to the second day; the second point was determined by adding the ratio of increase from the second to the third day to the ratio of increase from the first to the second day, and so on.

It may be seen from curve 1—"holder" process, pasteurized milk—that the ratio of increase was small during the first twenty-four hours, after which there was a rapid increase, then a small daily increase from that time on. The average bacterial counts in Table 20 show that this rapid increase on the second day took place when the bacterial count was low, 43,000 to 2,033,000, after which the increase was again slow. The same thing is shown in curve 2 with clean raw milk, except that the slow increase on the first day does not occur. In this case the rapid increase from 186,000 to 8,200,000 took place during the first twenty-four hours, then the increase was slow again. The "flash" process pasteurized milk as shown in curve 3 represents the same conditions. In curve 4, however, the ratios of increase rise slowly, no very sudden rise being seen in the curve. In this case the average initial count was 9,505,000, so that the period of rapid bacterial increase had passed and only a gradual, slow increase took place.

**Table 20.**—*Daily ratio of increase of bacteria in various kinds of raw and pasteurized milk.*

[The ratio is calculated in each case in comparison with the count of the preceding day.]

| Days. | Pasteurized milk, "holder" process. | | Clean raw milk. | | Dirty raw milk. | | Pasteurized milk, "flash" process. | |
|---|---|---|---|---|---|---|---|---|
| | Average bacterial count of 11 samples. | Ratio of increase. | Average bacterial count of 14 samples. | Ratio of increase. | Average bacterial count of 9 samples. | Ratio of increase. | Average bacterial count of 11 samples. | Ratio of increase. |
| 0 | 16,100 | .......... | 186,000 | .......... | 9,505,000 | .......... | 21,400 | .......... |
| 1 | 43,000 | 1 to 2.7 | 8,200,000 | 1 to 44.1 | 91,140,000 | 1 to 9.6 | 558,000 | 1 to 26.1 |
| 2 | 2,033,000 | 1 to 47.3 | 54,500,000 | 1 to 6.6 | 448,000,000 | 1 to 4.9 | 5,317,000 | 1 to 9.5 |
| 3 | 12,470,000 | 1 to 6.1 | 236,000,000 | 1 to 4.3 | 680,800,000 | 1 to 1.5 | 72,600,000 | 1 to 13.7 |
| 4 | 28,200,000 | 1 to 2.3 | 352,000,000 | 1 to 1.5 | .......... | .......... | .......... | .......... |
| 5 | 100,250,000 | 1 to 3.6 | 557,000,000 | 1 to 1.6 | .......... | .......... | .......... | .......... |
| 6 | 310,000,000 | 1 to 3.1 | .......... | .......... | .......... | .......... | .......... | .......... |

It can easily be seen how misleading ratios of increase as between pasteurized and raw milk may appear. When a comparison is made of curves 1 and 4 in figure 16, it would seem that the bacteria increased much more rapidly in the pasteurized than in the raw milk. But in this case the comparison would be fairer if curve 1 was considered from the point marked A, on the second day. At this point it may be seen that the bacterial count of the pasteurized milk was 2,033,000, while the raw milk as shown in curve 4 initially contained 9,505,000 per cubic centimeter. Curve 1 from the point A is about the same as curve 4 from the "0" point. In other words, the ratios of increase were about the same when compared from the periods at which their bacterial numbers were more nearly equal.

On the other hand, when raw milk had a low initial count, as was the case with curve 2, then curves 1 and 2 represent the conditions more fairly, and the conclusion would follow that bacteria increase, approximately, the same in pasteurized as in raw milk.

It is evident that if the initial counts are disregarded when comparing the ratios of pasteurized and raw milk in figure 16, any one of three contradictory conclusions can be arrived at. First, curves 1 and 4 would show that bacteria increased much faster in pasteurized than in raw milk. Second, curves 2 and 3 would show that bacteria increased faster in the raw milk than in the pasteurized. Third, curves 1 and 2 would show that the bacteria increased approximately the same in both milks.

The data in figure 16 were not intended to show in which milk the bacteria do actually reproduce the fastest; it was the purpose merely to indicate how little value can be placed upon ratios alone. The results tend to prove that bacteria do increase approximately the same in pasteurized as in raw milk, provided their initial counts are practically alike. However, this point can only be definitely determined by a large number of experiments with pasteurized and raw milks in which the initial total count and group percentages are approximately the same.

## LACTIC-ACID BACTERIA OF HIGH THERMAL DEATH POINT.

The pasteurized milk used in these experiments turned sour in every case, although the souring was delayed. This fact naturally suggests the question as to how lactic-acid bacteria survive pasteurization, or how they gain entrance to the milk after the process.

It is a generally accepted idea that pasteurization destroys the lactic-acid bacteria. Farrington and Russell[4] state that numerous experiments show the thermal death point of the lactic-acid bacteria to be in the neighborhood of 57.2° to 60° C. (135° to 140° F.) where the exposure was for ten minutes. It is not necessary to review here the numerous references to experiments showing the low resistance of the lactic-acid bacteria to heat, but it may be stated that the temperatures used in commercial pasteurization are always higher than the generally accepted thermal death point. On the other hand, here and there in the literature are references which indicate that there may be resistant strains of lactic-acid bacteria. Rogers[18] found that in milk pasteurized at 85° C. (185° F.) by the "flash" process and held at 20° C. (68° F.) lactic-acid bacteria occasionally survived which, after twenty-four hours, completely inhibited the peptonizing bacteria.

Marshall[14] states:

> It is largely supposed that in pasteurized milk the lactic-acid bacteria are killed. This is largely true but not universally. Sometimes the milk is curdled by acid formation without any digestion as in the usual lactic-acid fermentation.

Wolff[25] found living Güntheri organisms in milk pasteurized at 70° C. (158° F.) for one-half hour, but this occurred only when at the time of heating there had been a definite amount of acid formation, which he believed caused a coagulation in the form of a protecting envelope about the organisms, so that they were not only able to resist the pasteurizing temperature themselves, but could carry other organisms through with them.

Several other nonspore-forming organisms besides lactic-acid bacteria have been mentioned as resisting high temperatures.

Russell and Hastings[20] describe an organism capable of standing 76° C. (168.8° F.) for ten minutes. De Jong and de Graff,[10] working on various strains of *Bacillus coli* found some forms which required thirty minutes heating at 70° to 72° C. (158° to 161.6° F.) to destroy. Zelenski[26] also found some strains of *B. coli*, which resisted high temperatures, and showed that higher temperatures were required to kill the organism in milk than in broth. He suggested that the proteids or, perhaps, the presence of fat in milk formed a protecting envelope for the bacteria.

## EXPERIMENTS TO DETERMINE THERMAL DEATH POINT.

In order to determine if the lactic-acid bacteria in milk are capable of resisting high temperatures, a number of experiments were made by heating milk in Sternberg bulbs. The results of some of these experiments are tabulated in Table 21 below:

**Table 21.**—*The thermal death point of lactic-acid bacteria—Results of heating milk at various temperatures in Sternberg bulbs for thirty minutes.*

[+ = Positive result, indicated by typical solid curd.]

| Temperature. | Experiment I, whole milk. | Experiment II. | | Experiment III, whole milk. | Experiment IV, whole milk. | Experiment V. |
|---|---|---|---|---|---|---|
| | | Whole milk. | Skim milk. | | | |
| 60° C. (140° F.) | + + | + + | + + | | + + + + | + + |
| 62.8° C. (145° F.) | + + | + + | + + | | | |
| 65.6° C. (150° F.) | + + | + + | + + | | + + + + | + + |
| 68.3° C. (155° F.) | + + | + + | + + | | | |
| 71,1° C. (160° F.) | + + gas. | + + | + + | + | + + + +[a] | + + |
| 73.9° C. (165° F.) | | | | Partly digested acid curd. | Acid, coagulated, slightly peptonized.[b]<br>+ + + + | |
| 76.7° C. (170° F.) | | | | Partly digested slightly acid curd. | Decolorized curd, three-fourths peptonized.[c] | |

[a] The milk cultures on plating showed a large number of lactic-acid bacteria.

[b] The milk cultures on plating showed numerous lactic-acid bacteria.

[c] The milk cultures on plating showed no lactic-acid bacteria.

After heating the milk in the bulb it was introduced into tubes of sterile litmus milk. If the milk tubes showed typical solid curd decolorized except for the top acid ring, then the result was regarded as positive and is indicated in the table by the plus sign. As the table shows, all the milk tubes gave positive reactions when the bulbs were heated for thirty minutes at 71.1° C. (160° F.) and below, both in whole and skim milk. At 73.9° C. (165° F.) some of the tubes showed signs of peptonization. The milk in bulbs heated at 76.7° C. (170° F.) upon incubation in milk did not give the normal acid curd but either a slight acid or rennet curd with considerable digestion. A number of milk tubes inoculated from milk in bulbs heated to 71.1° C. (160° F.) were plated and showed the presence of a large number of colonies typical of the lactic-acid bacteria when plated on plus 1.5 litmus lactose agar and incubated at 37° C. (98.6° F.). Those heated to 73.9° C. (165° F.) showed numerous lactic-acid bacteria, while plates from milk inoculated from bulbs heated to 76.7° C. (170° F.) showed no lactic-acid colonies.

The results of these experiments correspond to those of numerous others in which milk was heated in cans and held at the same temperatures. It was observed in most cases that milk heated for thirty minutes at 71.1° C. (160° F.) and below gave a normal acid curd, while that heated at higher temperatures showed slight acid or even rennet curds with considerable digestion.

Besides heating the milk in bulbs for thirty minutes some was also heated for two minutes, which may serve to approximate the "flash" process. These results are shown in Table 22. It may be seen that with a short heating the lactic-acid bacteria may resist higher temperatures than when heated for thirty minutes.

TABLE 22.—*The thermal death point of lactic-acid bacteria—Results of heating milk at various temperatures in Sternberg bulbs for two minutes.*

[+ = Positive result, indicated by typical solid curd.]

| 73.9° C. (165° F.). | 76.7° C. (170° F.). | 79.4° C. (175° F.). | 82.2° C. (180° F.). |
|---|---|---|---|
| Acid, coagulated, slight whey.<br>+ + + + + | Same as 165° F.<br>+ + + + + | [a] Acid, coagulated, partly peptonized.<br>+ + + + + | [b] Partly peptonized, slightly acid.<br>+ + + + + |

[a] On plating out the coagulated milks, seven cultures picked off out of a total of ten gave the typical reaction of lactic-acid bacteria in milk.

[b] Seven cultures picked off plates made from the milk cultures turned milk acid, but did not coagulate it after seventy-two hours.

It must be noted that the milks used in these experiments contained large numbers of lactic-acid bacteria, the counts generally being high, due to hot weather.

From the heating experiments approximately 45 cultures of lactic-acid bacteria were isolated, all of which proved upon cultural tests to be typical of the streptococcus lacticus type of lactic-acid organism.

Numerous thermal death-point determinations showed that the death point of many of the lactic-acid organisms varied; the limit of resistance of some was between 65.6° C. (150° F.) and 71.1° C. (160° F.), while others stood thirty minutes heating in bulbs at temperatures above 71.1° C. (160° F.). One culture (will be called culture A) was selected as one of the organisms resisting the highest temperatures. It is typical of the streptococcus lacticus type in its cultural characteristics. Determinations of its thermal death point in milk were made every 2° F. upward from 58.9° C. (138° F.). In all cases the heating was carried on in Sternberg bulbs for thirty minutes. The death point was set at the first temperature above the temperature at which both control tubes showed growth within seventy-two hours.

Determinations made in milk, two sets in September, two in November, and two in December, showed the thermal death point to be 75.6° C. (168° F.). The interval between the determinations shows that the high resistance is a permanent character and not a temporary freak of the organism. The thermal death point of culture A in broth was 74.4° C. (166° F.), using the same period of heating. Experiments were tried, using 18 per cent and 20 per cent cream, but no increase in the thermal death point was observed. The thermal death point with a ten-minute exposure was found to be 77.8° C. (172° F.).

The effect of temperature on the bacterial numbers of culture A is shown in Table 23.

TABLE 23.—*The thermal death point of lactic-acid bacteria—Effect of heating on the numbers of lactic organisms in culture A—Milk heated in small flasks submerged to the neck in water bottle for thirty minutes—Temperature readings taken directly in the milk.*

| Temperature. | Bacteria per c. c. before heating. | Bacteria per c. c. after heating for 30 minutes. | Reduction. |
|---|---|---|---|
| | | | *Per cent.* |
| 60° C. (140° F.).. | 58,000,000 | 63,000,000 | 0 |
| | 64,500,000 | 51,000,000 | |
| | [a] 61,250,000 | 57,250,000 | |
| 65.6° C. (150° F.).. | 41,000,000 | 41,700,000 | 0 |
| 71.1° C. (160° F.).. | 244,000,000 | 133,000,000 | 53.07 |
| | 315,000,000 | 138,000,000 | |
| | [a] 284,500,000 | 135,500,000 | |

[a] Average.

Thirty minutes heating at 60° C. (140° F.) or 65.6° C. (150° F.) had no reducing effect, while at 71.1° C. (160° F.) the percentage reduction was only 53.07 per cent.

Even the "majority" thermal death point of culture A as suggested by Gage and Stoughton [8] would be very high as compared with the ordinary nonspore-forming bacteria. It is evident that these high-temperature-resisting organisms are different strains of the common lactic-acid bacteria and that they play an important part in pasteurized milk. These organisms, together with other species of nonspore-forming bacteria of high thermal death point which we have isolated, will be the subject of further investigation.

In connection with the determination of the thermal death point of bacteria it should be mentioned that it is necessary to keep the acidity of the media down as low as possible at the time of heating when the organism is grown in milk or broth. It was found that the thermal death point of culture A was lowered a number of degrees by using a culture of sugar broth of such an age that the acidity was high. In some unpublished work by Davis of this laboratory it was found that as the acidity increased the thermal death point decreased.

## PER CENT OF LACTIC-ACID BACTERIA CAPABLE OF WITHSTANDING HIGH TEMPERATURES.

A number of experiments have been made to determine the approximate percentage of lactic-acid bacteria which were capable of standing high temperatures. Raw milk was heated in flasks in the laboratory for thirty minutes at 60° C. (140° F.) and 65.6° C. (150° F.) and then plated on litmus lactose agar reaction plus 1.5 and incubated at 37° C. (98.6° F.) for forty-eight hours. The results are shown in Table 24.

TABLE 24.—*Showing percentage of lactic-acid bacteria of high thermal death point in milk.*

| No. | Kind of milk. | Pasteurized in laboratory in flasks for 30 minutes at— | Total bacteria per c. c. | Acid bacteria per c. c. | Percentage of acid colonies. | Percentage of reduction of acid colonies. | Remarks. |
|---|---|---|---|---|---|---|---|
| 1 | Raw........ | .................. | 146,000 | 20,000 | 13.6 | .......... | |
| | | 65.6° C. (150° F.). | 1,080 | 480 | 44.4 | 97.6 | |
| 2 | .....do...... | .................. | 620,000 | 100,000 | 16.1 | .......... | |
| | | 60° C. (140° F.).. | 470 | 70 | 14.8 | 99.93 | |
| | | 65.6° C. (150° F.). | 280 | 40 | 14.2 | 99.96 | |
| 3 | .....do...... | .................. | 4,520,000 | 3,930,000 | 86.9 | .......... | Milk was held in refrigerator for 24 hours before heating. |
| | | 60° C. (140° F.).. | 66,000 | 12,000 | 18.1 | 99.69 | |
| | | 65.6° C. (150° F.). | 3,300 | 1,400 | 42.4 | 99.94 | |
| 4 | .....do...... | .................. | 122,000 | 48,000 | 39.3 | .......... | |
| | | 60° C. (140° F.).. | 9,000 | 4,900 | 54.4 | 89.79 | |
| | | 65.6° C. (150° F.). | 420 | 40 | 9.5 | 99.91 | |
| 5 | Pasteurized. | .................. | 335,000 | 136,000 | 40.5 | .......... | Pasteurized milk treated same as raw milk. |
| | | 60° C. (140° F.).. | 23,800 | 8,700 | 36.5 | 93.60 | |
| | | 65.6° C. (150° F.). | 9,200 | 0 | 0 | 100.00 | |
| 6 | Raw........ | .................. | 720,000 | 215,000 | 29.8 | .......... | |
| | | 60° C. (140° F.).. | 2,100 | 900 | 42.8 | 99.58 | |
| | | 65.6° C. (150° F.). | 70 | 10 | 14.28 | 99.99 | |
| 7 | .....do...... | .................. | 31,500 | 6,400 | 20.3 | .......... | |
| | | 60° C. (140° F.).. | 5,270 | 1,210 | 22.9 | 81.09 | |
| | | 65.6° C. (150° F.). | 5,120 | 130 | 2.5 | 97.96 | |
| 8 | .....do...... | .................. | 490,000 | 165,000 | 33.6 | .......... | |
| | | 60° C. (140° F.).. | 50,600 | 1,270 | 2.50 | 99.23 | |
| | | 65.6° C. (150° F.). | 1,700 | 280 | 16.4 | 99.83 | |
| 9 | .....do...... | .................. | 90,000 | 8,000 | 8.8 | .......... | |
| | | 60° C. (140° F.).. | 5,700 | 250 | 4.3 | 96.87 | |
| | | 65.6° C. (150° F.). | 4,700 | 250 | 5.3 | 96.87 | |
| 10 | .....do...... | .................. | 24,900 | 4,600 | 18.4 | .......... | |
| | | 60° C. (140° F.).. | 3,020 | 600 | 21.85 | 85.65 | |
| | | 65.6° C. (150° F.). | 1,710 | 10 | .58 | 99.78 | |
| 11 | .....do...... | .................. | 102,000,000 | 65,000,000 | 63.7 | .......... | Milk held 3 days at 10° C. (50° F.) before heating. |
| | | 60° C. (140° F.).. | 2,050 | 1,580 | 77.0 | 99.999 | |
| | | 65.6° C. (150° F.). | 490 | 440 | 89.7 | 99.999 | |
| 12 | .....do...... | .................. | 1,560,000 | 740,000 | 47.4 | .......... | |
| | | 60° C. (140° F.).. | 460 | 320 | 69.5 | 99.95 | |
| | | 65.6° C. (150° F.). | 110 | 80 | 72.7 | 99.98 | |

In making the acid count only those colonies were included which were typical of the lactic-acid bacteria; that is to say, small acid colonies. It was found, however, that the count included a few colonies that were not true lactic forms, but were cocci which may belong to the group of organisms coming from the udder of the cow. This point is to be the object of further study. Sample 5 was a pasteurized milk, but even in that case after heating again at 60° C. (140° F.) 36.5 per cent of the total bacteria left were acid formers. In samples 11 and 12, where the initial count was very high, the per cent of acid colonies after heating to 60° C. (140° F.) and 65.6° C. (150° F.) was 69.5 and 72.7 per cent, respectively, of the total bacteria. Where the initial count was lower the percentage of acid colonies in the heated milk was correspondingly low. The percentage remaining in the milks varies considerably, as may be seen from the table, but if the percentages are averaged it will be found that the acid formers constituted 34.4 per cent of the total in raw milk; in the milk heated for thirty minutes at 60° C. (140° F.) the percentage was 32.8, and when heated at 65.6° C. (150° F.) it was 28.4 per cent of the total bacteria.

It is apparent that on the average the proportion of acid bacteria does not change very much when milk is heated at the temperatures used in these experiments. It might be expected in view of these facts that the pasteurized milk should sour as normally as does the raw milk, but the souring was delayed, due to the small numbers of the acid bacteria of high thermal death point and to their relatively slow growth.

In the last column of Table 24 are shown the percentages of acid bacteria destroyed during heating. The remainder represents the heat-resisting forms. At 60° C. (140° F.) the range in the various samples is from 0.001 to 18.91 per cent, and the average number of heat-resisting lactic organisms is 4.8 per cent. At 65.6° C. (150° F.) the range is from 0.001 to 3.13 per cent, with an average of 0.74 per cent. These figures are of course only approximate, but serve to show that about 4.8 per cent of the lactic-acid bacteria were able to stand heating to 60° C. (140° F.), while approximately 0.74 per cent were not destroyed at 65.6° C. (150° F.) for thirty minutes.

These results suggest that heat-resisting strains may occur in pathogenic bacteria as they do among the lactic-acid bacteria. The thermal death points of pathogenic bacteria have been determined in but few instances, as has been the case with the lactic-acid forms. That of the typhoid bacillus might, for example, be determined if urine from a number of typhoid patients were heated in bulbs, as was for the milk in these experiments. It might thus be possible to isolate strains of the typhoid bacillus having a high thermal death point. However, the possibility of such strains existing does not in any way detract from the value of pasteurization as a protection against pathogenic bacteria, for the reason that only a very few pathogenic organisms are ever present in milk and the possibility of heat-resisting strains in that small number is infinitely small, because if such exist they form only a minute percentage of the total. This point is mentioned merely as a suggestion for those interested in the study of pathogenic bacteria.

## SUMMARY AND CONCLUSIONS.

The results in this paper hold only for commercially pasteurized milk. By commercial pasteurization is meant milk heated from 60° C. (140° F.) to 65.6° C. (150° F.) in the "holder" process, or up to 71.1° C. (160° F.) in the "flash" process. At the present time the tendency is to use low temperatures with the "holder" process, and in commercial work it is doubtful if temperatures will ever be used universally in either process higher than those above mentioned. When higher temperatures are used the cream line is liable to be destroyed, a cooked taste may be produced which injures the sale of the milk, and the cost of pasteurization is increased by the use of more steam. It is not reasonable, therefore, to expect the use of high temperatures in commercial pasteurization. Arbitrary limits could be set, as 60° C. (140° F.) to 62.8° C. (145° F.) and even perhaps to 65.6° C. (150° F.) for the "holder" process and 71.1° C. (160° F.) to 73.9° C. (165° F.) for the "flash" process, at which temperatures milk when heated under commercial conditions may be expected eventually to sour, and the bacterial content will be comparable to the average group curves for pasteurized milk as shown in this paper. If higher temperatures are used a degree of heat may be reached which will result in the destruction of all but spores, which, when allowed to develop, will undoubtedly produce peptonization of the milk. Granting that 60° C. (140° F.) for twenty minutes is sufficient to destroy pathogenic organisms, it is believed it would nevertheless be advisable in commercial work to use a temperature a little higher, as 62.8° C. (145° F.) and for thirty minutes. That temperature would be sufficiently high to afford protection against pathogenic bacteria and yet would probably leave in the milk the maximum proportion of lactic-acid bacteria, and the group proportions would be very similar to those of all grades of market milk.

### CONCLUSIONS.

1. Commercially pasteurized milk always sours, because of the development of lactic-acid bacteria which on account of their high thermal death point survive pasteurization, and perhaps in some cases because of subsequent infection with acid-forming bacteria during cooling and bottling.

The acid development in an efficiently pasteurized milk is about the same as that in a clean raw milk. But sometimes a strong, old taste develops which is probably due to the development of alkali or inert bacteria. The old taste, however, is not characteristic of pasteurized milk, for it may be noticed as well in clean raw milk when held under similar conditions. The less efficient the pasteurizing process the more closely does the acid increase of the heated milk approach that of a dirty raw milk.

2. The relative proportion of the groups of peptonizing, lactic acid, and alkali or inert bacteria is approximately the same in efficiently pasteurized milk as it is in clean raw milk. In both cases the alkali or inert forms constitute the largest group, the lactic-acid bacteria next, while the peptonizers are in the minority. When both of these milks—the efficiently pasteurized and clean raw milk—are held, the group relations change; but if the changes which take place are compared it will be found that they are the same in each. At the time of souring, the group proportions have changed so that the lactic-acid bacteria constitute the largest group with the alkali or inert forms next in order and the peptonizers in the smallest proportion as initially. In both of these milks the group of peptonizers may increase slightly in its proportion to the other two groups during the first two days, but it then gradually decreases and always forms the smallest group.

When milk is less efficiently pasteurized the position of the groups may be reversed so that the lactic-acid bacteria constitute the largest group with the alkali or inert forms next in order, but here again the peptonizers form the smallest proportion of the total bacteria. This group arrangement is the same in a dirty raw milk.

The more efficient the pasteurization, the smaller the percentage of lactic-acid bacteria; and, similarly, the cleaner the raw milk, the smaller the percentage of lactic-acid bacteria.

3. The peptonizing bacteria are present in smaller numbers in the inferior grades of commercially pasteurized milk during the first twenty-four hours after receiving than in raw milk of the same quality, and the peptonizers may increase to slightly higher numbers in the pasteurized milk when held several days than in the raw milk of high initial lactic-acid bacteria content; but it should be remembered in this connection that milk is usually consumed within twenty-four hours after delivery. The number of peptonizers in a good grade of commercial pasteurized milk on the initial count, and on succeeding days is approximately the same as in a clean raw milk when held under similar temperature conditions.

4. Lactic-acid bacteria of high thermal death point are found in milk and may be easily isolated by special methods of procedure. From these experiments it was found that when milk is heated for

thirty minutes at 60° C. (140° F.) and plated, the percentage of acid-forming organisms that resisted the heating ranged from 0.001, to 18.91, the average being 4.8 per cent of the total acid colonies. When heated at 65.6° C. (150° F.) the range is from 0.001 to 3.13 per cent, the average being 0.74 per cent of the total bacteria. It must be remembered that these figures are based upon acid colonies, and these are not necessarily all true lactic-acid bacteria.

The thermal death point of one lactic-acid organism which was isolated from milk is 74.4° C. (166° F.) in broth and 75.6° C. (168° F.) in milk when heated in Sternberg bulbs for thirty minutes. When heated for ten minutes in milk the thermal death point is 77.8° C. (172° F.).

These heat-resisting lactic-acid bacteria play an important part in pasteurized milk and undoubtedly account to a large extent for its ultimate souring.

5. All milk, whether pasteurized or raw, must necessarily be infected during cooling and bottling by bacteria in the receiving tanks, in the pipes, on the cooler, and in the bottles; but the low bacterial counts obtained from pasteurized milk in these investigations show that the reinfection must have been very small.

6. It is manifestly unfair to conclude that bacteria increase faster in pasteurized than in raw milk, simply from a comparison of the ratios of bacterial increase. If a pasteurized milk with a low initial count is compared with a raw milk of high bacterial content then the ratios of increase may show that the bacteria in the heated milk do increase faster; but if the same pasteurized milk is compared with a clean raw milk with a low count, then the ratios of increase will be found to be approximately the same. From the results of this investigation it is evident that bacterial increase in an efficiently pasteurized and a clean raw milk is about the same when the samples of milk are held under similar temperature conditions. This question of the relative growth of bacteria in raw and pasteurized milk can be properly settled only by a long series of comparisons of samples of milk with approximately the same bacterial count and similar bacterial group percentages.

7. The "holder" process of pasteurization is superior to the "flash" process. With the "holder" process a high efficiency may be obtained with a low temperature, while to obtain the same efficiency with the "flash" process a high temperature would be required. A temperature of 62.8° C. (145° F.) for thirty minutes seems best adapted for efficient pasteurization.

8. Considering the low counts of bottled commercially pasteurized milk and the similarity of the bacterial group proportions to those of clean raw milk, the former can not be classed from a bacteriological point of view as inferior to commercial raw milk. Pasteurized and

raw milk should, however, always be bottled and should not be allowed to be sold as "loose" milk from stores.

9. Pasteurization should always be under the control of competent men who understand the scientific side of the problem. It is believed that ignorance of fundamental bacteriological facts often accounts for inefficient results rather than a willful lack of care on the part of the dairyman.

## ACKNOWLEDGMENTS.

In conclusion, it is desired to acknowledge the kindness of officials of the boards of health in Boston and New York in furnishing information regarding the milk supply, and to express our thanks to the officials of various milk companies who have allowed milk samples to be taken at their plants.

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# APPENDIX.

## COMMERCIAL MILK.

**In the succeeding tables "0" days means the day the milk was received at the laboratory, which is equivalent to the time the consumer would receive it.**

TABLE I.—*Acidity and bacterial content of commercially pasteurized milk in a small city—Milk held at 10° C. (50° F.).*

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. |
|---|---|---|---|---|---|---|
| 27 | 0 | 0.13 | 20,250,000 | 800,000 | 10,700,000 | 2,200,000 |
| | 1 | .18 | 80,960,000 | 1,300,000 | 51,200,000 | ... |
| | 2 | .25 | ... | ... | ... | ... |
| 29 | 0 | .14 | 1,212,000 | 140,000 | 730,000 | ... |
| | 1 | .15 | 13,500,000 | 2,000,000 | 11,700,000 | 600,000 |
| | 2 | .19 | ... | ... | ... | ... |
| 31 | 0 | .17 | 6,310,000 | 310,000 | 6,200,000 | 2,200,000 |
| | 1 | .17 | 42,500,000 | 1,200,000 | 19,700,000 | 16,300,000 |
| | 2 | .24 | ... | ... | ... | ... |
| 33 | 0 | .16 | 14,830,000 | 400,000 | 12,600,000 | 700,000 |
| | 1 | .19 | 98,000,000 | 800,000 | 71,300,000 | ... |
| | 2 | .40 | ... | ... | ... | ... |
| 35 | 0 | .14 | 240,000 | 10,000 | 63,000 | 37,000 |
| | 1 | .16 | 715,000 | 900,000 | 200,000 | [a] 200,000 |
| | 2 | .17 | ... | ... | ... | ... |
| 37 | 0 | .14 | 35,200 | 1,200 | [b] 29,000 | ... |
| | 1 | .16 | 76,500 | 3,000 | [b] 96,000 | ... |
| 39 | 0 | .14 | 25,000 | ... | ... | ... |
| | 1 | .16 | 68,650 | ... | ... | ... |
| 41 | 0 | .16 | 980,000 | ... | ... | ... |
| | 1 | .16 | ... | ... | ... | ... |
| 43 | 0 | .17 | 33,350 | ... | ... | ... |
| | 1 | .17 | 45,400 | ... | ... | ... |

[a] Dilution on gelatin plates was too high; differential count is of no value.

[b] Might have been alkali formers or inert forms.

**TABLE II.**—*Acidity and bacterial content of commercially pasteurized milk in a small city—Milk held at room temperature 22-25° C. (71.6-77° F.).*

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 28 | 0 | 0.17 | 21,500,000 | 700,000 | 5,600,000 | 2,700,000 | A large proportion of these may have been of the Lactis aerogenes type. |
| | 1 | .78 | 1,861,000,000 | 2,000,000 | 1,180,000,000 | ............ | Curdled; gas in curd. |
| 30 | 0 | .14 | 3,820,000 | 800,000 | 2,700,000 | 220,000 | |
| | 1 | .78 | 1,774,000,000 | 1,000,000 | [a] 1,600,000,000 | ............ | Do. |
| 32 | 0 | .17 | 38,030,000 | 500,000 | 25,600,000 | 2,400,000 | A large proportion may have been Lactis aerogenes. |
| | 1 | .90 | 390,000,000 | .............. | [b] 346,000,000 | ............ | Do. |
| 34 | 0 | .17 | 6,155,000 | 1,000,000 | 4,600,000 | 2,500,000 | A large proportion may have been Lactis aerogenes; sour, curdled. |
| | 1 | .62 | 1,024,000,000 | 5,000,000 | 998,000,000 | 8,000,000 | |
| 36 | 0 | .15 | 154,000 | 17,500 | 70,000 | 57,000 | |
| | 1 | .57 | 1,364,000,000 | 25,000,000 | [c] 1,040,000,000 | ............ | Not curdled, but sour. |
| 38 | 0 | .14 | 34.250 | 1,500 | 2,500 | (30,500)<br>2,600 | May have been lactic-acid bacteria. |
| | 1 | .67 | 1,304,000,000 | .............. | [d] 1,000,000,000 | ............ | Curdled; gas in curd. |
| 40 | 0 | .15 | 24,700 | 100 | .............. | 6,700 | |
| | 1 | .19 | 108,600,000 | ([e]) | [f] 98,800,000 | ............ | Counts from agar plates; temperature of room low probably accounts for slow acid formation. |

[a] 29,000,000 Lactis aerogenes.
[b] 36,000,000 Lactis aerogenes.
[c] On agar.
[d] 1,000,000 Lactis aerogenes.
[e] Gelatin plate lost.
[f] 9,800,000 Lactis aerogenes.

**TABLE III.**—*Pasteurized milk in a small city—Total count and percentage of different groups—Milk held at 10° C. (50° F.).*

| Sample No. | Age of milk in days. | Total bacteria per c. c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|
| 27 | 0 | 13,700,000 | 5.83 | 78.10 | 16.05 |
| | 1 | 52,500,000 | 2.47 | 97.52 | ............ |
| 29 | 0 | 870,000 | 16.09 | 83.90 | ............ |
| | 1 | 14,300,000 | 13.98 | 81.81 | 4.19 |
| 31 | 0 | 8,610,000 | 2.43 | 72.00 | 25.55 |
| | 1 | 37,200,000 | 3.22 | 52.95 | 43.81 |
| 33 | 0 | 13,700,000 | 2.91 | 91.97 | 5.10 |
| | 1 | 72,100,000 | 1.08 | 98.89 | ............ |
| 35 | 0 | 110,000 | 9.09 | 57.27 | 33.63 |
| | 1 | ............ | ............ | ............ | ............ |
| 37 | 0 | 30,200 | 3.97 | 96.02 | ............ |

**TABLE IV.**—*Pasteurized milk in a small city—Total count and percentage of different groups—Milk held at room temperature 22° to 25° C. (71.6° to 77° F.).*

| Sample No. | Age of milk in days. | Total bacteria per c. c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|
| 28 | 0 | 9,000,000 | 7.77 | 62.22 | 30.00 |
| | 1 | 1,182,000,000 | 1.69 | 99.83 | ............ |
| 30 | 0 | 3,720,000 | 21.50 | 72.58 | 5.91 |
| | 1 | 1,630,000,000 | .061 | 99.93 | ............ |
| 32 | 0 | 28,500,000 | 1.754 | 89.82 | 8.42 |
| 34 | 0 | 8,100,000 | 12.34 | 56.79 | 30.86 |
| | 1 | 1,011,000,000 | .49 | 98.71 | .79 |
| 36 | 0 | 144,500 | 12.11 | 48.44 | 39.44 |
| | 1 | 1,065,000,000 | 2.34 | 97.65 | ............ |
| 38 | 0 | 37,100 | 4.04 | 6.73 | 89.21 |

**TABLE V.**—*Raw and pasteurized milk at Boston, Mass., examined during November and December, 1908, and January, 1909—Milk held at 10° C. (50° F.).*

PASTEURIZED MILK.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per. c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 45 | 0 | ........ | 22,800 | 4,900 | 22,400 | 9,100 | Samples 45 to 63, inclusive, from dairy B, pasteurized 140°-150° F. (68°-65.6° C.), "flash" process. |
| | 1 | 0.18 | 137,000 | 12,000 | 81,000<br>L. A.[a] 6,000 | 43,000 | |
| 47 | 0 | .18 | 29,000 | 4,800 | 13,200 | 8,300 | Large number of acid colonies on agar. |
| | 1 | .18 | 393,000 | ............ | L. A. 2,000 | | |
| 49 | 0 | .19 | 39,500 | 3,400 | 33,600 | 3,700 | |
| | 1 | .20 | 360,000 | 30,000 | 124,000<br>L. A. 6,000 | 100,000 | |
| 51 | 0 | .20 | 200,000 | 7,000 | 57,000<br>L. A. 71,000 | 70,000 | |
| | 1 | .21 | 2,000,000 | 100,000 | 800,000<br>L. A. 600,000 | 600,000 | |
| 53 | 0 | .18 | 106,000 | 6,000 | 88,000 | 30,000 | |
| | 1 | | | | | | |
| 55 | 0 | .24 | [b] 117,000 | 12,000 | 65,000 | 40,000 | |
| | 1 | .27 | 360,000 | 150,000 | 10,000<br>L. A. 50,000 | 70,000 | |
| 57 | 0 | .28 | 120,000 | 10,000 | 140,000<br>L. A. 40,000 | 30,000 | |
| | 1 | .33 | 2,700,000 | 500,000 | 4,300,000<br>L. A. 400,000 | 2,600,000 | |
| 59 | 0 | ........ | 586,000 | 45,000 | 414,000 | 70,000 | |
| | 1 | .19 | 7,620,000 | 330,000 | 7,040,000 | 450,000 | |
| 61 | 0 | .19 | 218,000 | 70,000 | 79,000<br>L. A. 15,000 | 50,000 | |
| | 1 | .21 | 9,330,000 | 800,000 | 1,000,000<br>L. A. 800,000 | 900,000 | |
| 63 | 0 | .18 | [b] 204,000 | 38,000 | 22,000<br>L. A. 48,000 | 96,000 | |
| | 1 | .19 | [b] 950,000 | 350,000 | 140,000<br>L. A. 60,000 | 400,000 | 270,000 of total peptonizing bacteria liquefied gelatin only slightly. |

[a] L. A. means B. lactis aerogenes. The colonies growing on gelatin plates which looked like typical colonies of B. lactis aerogenes were included in the counts.

[b] In these cases gelatin was used instead of agar.

TABLE V.—*Raw and pasteurized milk at Boston, Mass., examined during November and December, 1908, and January, 1909—Milk held at 10° C. (50° F.)*—Continued.

### PASTEURIZED MILK—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per. c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 65 | 0 | 0.24 | 22,400 | 20,000 | 6,000 | 32,000 | Samples 65 to 89, inclusive from dairy A pasteurized at 60°-65.6° C. (140° - 150° F.) "holder" process. |
|  | 1 | .29 | 3,500,000 | 1,900,000 | 0 | 600,000 |  |
| 67 | 0 | .30 | 118,000 | 6,000 | 96,000<br>L. A. 11,000 | 3,000 |  |
|  | 1 | .33 | 39,900,000 | 1,400,000 | 10,800,000<br>L. A. 200,000 | 6,300,000 |  |
| 69 | 0 | ........ | 41,000 | 2,700 | 2,200<br>L. A. 400 | 40,000 | Some alkali forms, probably lactic-acid bacteria. |
|  | 1 | .18 | 880,000 | 90,000 | 10,000 | 690,000 | Do. |
| 71 | 0 | .18 | 46,550 | 3,000 | 34,000 | 11,700 |  |
|  | 1 | .19 | 214,000 | 100,000 | 250,000 | 80,000 |  |
| 73 | 0 | .18 | 36,000 | 1,000 | 18,300 | 15,400 |  |
|  | 1 | .19 | [a] 1,970,000 | 120,000 | ........ | 1,850,000 | Probably the alkali formers had a large percentage of acid forms. |
| 75 | 0 | .18 | 69,200 | 15,000 | 145,000 | 15,000 |  |
|  | 1 | .18 | 1,750,000 | 100,000 | 660,000 | 380,000 |  |
| 77 | 0 | .18 | 62,800 | 2,800 | 3,400 | 50,000 |  |
|  | 1 | .20 | 800,000 | 100,000 | ........ | 1,300,000 | Dilution too high. |
| 79 | 0 | .18 | 29,300 | 600 | 25,000<br>L. A. 8,000 | 10,000 |  |
|  | 1 | .18 | 50,000 | ........ | 30,000 | ........ | Do. |
| 81 | 0 | .18 | 17,900 | 0 | 36,000 | 5,000 | No peptonizing bacteria in 1:1,000 dilution. |
|  | 1 | .18 | 120,000 | ........ | ........ | ........ | Gelatin liquefied. |
| 83 | 0 | .18 | 45,300 | 1,000 | 22,000 | 1,000 |  |
|  | 1 | .18 | ........ | ........ | ........ | ........ | Plates contaminated. |
| 85 | 0 | .18 | 6,000 | 0 | 6,000 | 3,000 | No peptonizing bacteria in 1:100 dilution. |
|  | 1 | ........ | ........ | ........ | ........ | ........ |  |
| 87 | 0 | .18 | 19,700 | 3,000 | 32,000 | ........ | Lactic-acid bacteria and alkali formers indistinguishable. |
|  | 1 | .18 | ........ | ........ | ........ | ........ | Plates contaminated. |
|  | 2 | ........ | ........ | ........ | ........ | ........ |  |
|  | 3 | .31 | 467,000,000 | ........ | 350,000,000<br>(Agar.) | ........ | Gelatin lost. |
|  | 4 | .42 | 656,000,000 | ........ | ........ | ........ | Slightly sour, cheesy; total bacteria mostly acid. |
| 89 | 0 | .18 | ........ | ........ | ........ | ........ | Plates contaminated. |
|  | 1 | .18 | [a] 132,000 | 21,000 | 45,000 | 66,000 |  |
|  | 2 | ........ | ........ | ........ | ........ | ........ |  |
|  | 3 | .19 | [a] 26,100,000 | 2,700,000 | 2,800,000<br>L. A. 600,000 | 20,000,000 |  |
|  | 4 | .41 | [a] 300,000,000 | 6,000,000 | 200,000,000<br>L. A. 30,000,000 | 64,000,000 |  |
| 123 | 0 | .20 | 140,000 | ........ | ........ | ........ | Samples 123-133, inclusive, from dairy A pasteurized 60°-65.6° C. (140°-150° F.) "holder" process. |
|  | 1 | ........ | ........ | ........ | ........ | ........ |  |
|  | 2 | .24 | 15,000,000 | 0 | 0 | 19,200,000 | No peptonizing or lactic acid bacteria in 1:100,000 dilution. |
|  | 3 | .39 | 21,300,000 | 3,400,000 | L. A. 1,000,000 | ........ | Slightly sour. |
|  | 4 | ........ | 184,000,000 | 6,000,000 | 56,000,000 | 76,000,000 |  |

[a] In these cases gelatin was used instead of agar.

TABLE V.—*Raw and pasteurized milk at Boston, Mass., examined during November and December, 1908, and January, 1909—Milk held at 10° C. (50° F.)*—Continued.

PASTEURIZED MILK—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 125 | 0 | 0.14 | 10,240,000 | .......... | .......... | .......... | Gelatin plates liquefied. |
| | 1 | .18 | 148,000,000 | 600,000 | 27,400,000<br>L. A. 1,800,000 | 9,900,000 | |
| | 2 | ....... | 200,000,000 | 9,000,000 | 43,000,000<br>L. A. 30,000,000 | 15,000,000 | |
| | 3 | .36 | .......... | .......... | .......... | .......... | Slightly sour. |
| 129 | 0 | .14 | 14,100 | 2,000 | 0 | 7,000 | No lactic-acid bacteria in 1:1,000 dilution. |
| | 1 | .15 | [a]2,400,000 | 700,000 | 0 | 1,700,000 | No lactic-acid bacteria in 1:100,000 dilution. |
| | 2 | .15 | [a]35,000,000 | 10,000,000 | L. A. 1,000,000 | 24,000,000 | |
| | 3 | ....... | .......... | .......... | .......... | .......... | |
| | 4 | .28 | [a]263,000,000 | 21,000,000 | 172,000,000<br>L. A. 15,000,000 | 55,000,000 | |
| | 5 | .45 | [a]700,000,000 | 50,000,000 | 520,000,000<br>L. A. 30,000,000 | 100,000,000 | Slightly sour. |
| 131 | 0 | .14 | [a]35,000 | 8,000 | 1,000 | 26,000 | No lactic-acid bacteria in 1:100,000 dilution. |
| | 1 | .14 | [a]2,400,000 | 200,000 | 0 | 2,200,000 | |
| | 2 | ....... | .......... | .......... | .......... | .......... | |
| | 3 | .15 | [a]77,000,000 | 6,000,000 | 12,000,000<br>L. A. 10,000,000 | 49,000,000 | |
| | 4 | .19 | [a]400,000,000 | 10,000,000 | 100,000,000 | 290,000,000 | |
| | 5 | .32 | .......... | .......... | .......... | .......... | Slightly sour. |
| 133 | 0 | .14 | [a]12,000 | 1,500 | 500 | 10,000 | |
| | 1 | ....... | .......... | .......... | .......... | .......... | |
| | 2 | .14 | [a]14,400,000 | 1,400,000 | 100,000<br>L. A. 100,000 | 12,800,000 | |
| | 3 | .19 | [a]54,000,000 | 5,000,000 | 16,000,000 | 33,000,000 | |
| | 4 | .36 | .......... | .......... | .......... | .......... | Slightly sour. |
| 91 | 0 | .20 | 74,880,000 | .......... | .......... | .......... | Gelatin plates liquefied. Samples 91-92, inclusive, from dairy C; total bacteria mostly acid colonies; pasteurised 71.1°-73.8° C. (160°-165° F.) "flash" process. |
| | 1 | .34 | 443,000,000 | .......... | .......... | .......... | |
| | 2 | .87 | .......... | .......... | .......... | .......... | |
| 93 | 0 | .19 | 3,700,000 | 800,000 | 2,500,000 | 0 | No alkali formers in 1:100,000 dilution. |
| | 1 | .20 | 95,000,000 | 2,900,000 | 1,000,000 | 7,600,000 | Sour on fourth day. |
| 95 | 0 | .27 | 17,000,000 | 1,700,000 | 100,000 | 4,000,000 | |
| | 1 | .41 | 475,000,000 | 10,000,000 | 120,000,000<br>L. A. 40,000,000 | 20,000,000 | |
| | 2 | .72 | .......... | .......... | .......... | .......... | Sour. |
| 97 | 0 | .19 | 4,300,000 | .......... | .......... | .......... | Gelatin liquefied. |
| | 1 | .27 | 17,500,000 | 900,000 | 18,000,000<br>L. A. 2,300,000 | 1,200,000 | |
| | 2 | .49 | 202,000,000 | 10,000,000 | 160,000,000<br>L. A. 6,000,000 | 10,000,000 | |
| | 3 | .81 | .......... | .......... | .......... | .......... | Sour and cheesy. |
| 99 | 0 | .24 | 1,580,000 | .......... | .......... | .......... | Gelatin liquefied. |
| | 1 | .26 | 71,000,000 | 200,000 | 9,400,000 | 1,700,000 | |
| | 2 | .49 | .......... | .......... | .......... | .......... | Slightly sour. |
| 101 | 0 | .18 | 2,200,000 | 100,000 | 420,000 | 360,000 | |
| | 1 | .22 | 52,250,000 | .......... | .......... | .......... | Gelatin liquefied; total bacteria mostly acid colonies. |
| 103 | 0 | .22 | 12,000 | .......... | .......... | .......... | Gelatin liquefied. |
| | 1 | .26 | 106,000,000 | 8,000,000 | 45,000,000 | 33,000000, | |
| | 2 | .50 | 239,000,000 | 7,000,000 | 165,000.000<br>L. A. 16,000,000 | 20,000,000 | Slightly sour. |

[a] In these cases gelatin was used instead of agar.

TABLE V.—*Raw and pasteurized milk at Boston, Mass., examined during November and December, 1908, and January, 1909—Milk held at 10° C. (50° F.)*—Continued.

PASTEURIZED MILK—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 105 | 0 | 0.18 | 87,000 | ........ | ........ | ........ | Gelatin liquefied. |
| | 1 | .21 | 120,000,000 | 3,000,000 | 15,000,000 | 14,000,000 | |
| | 2 | .40 | 309,000,000 | 20,000,000 | 250,000,000 | 0 | Slightly sour; no alkali formers in 1 : 10,000,000 dilution. |
| 107 | 0 | .19 | 1,760,000 | 200,000 | 600,000<br>L. A. 100,000 | 200,000 | |
| | 1 | .23 | 33,500,000 | 600,000 | 20,000,000<br>L. A. 3,200,000 | 3,400,000 | |
| | 2 | .36 | 65,000,000 | 1,000,000 | 50,000,000<br>L. A. 10,000,000 | 3,000,000 | Slightly sour. |
| 109 | 0 | .19 | 2,660,000 | 210,000 | 60,000 | 1,180,000 | |
| | 1 | .25 | 44,200,000 | 7,000,000 | 10,000,000<br>L. A. 14,000,000 | 200,000,000 | |
| | 2 | .36 | 60,000,000 | 2,000,000 | 46,000,000<br>L. A. 1,000,000 | 7,000,000 | Do. |
| 111 | 0 | .19 | 4,900,000 | 3,000,000 | 700,000<br>L. A. 300,000 | 3,000,000 | |
| | 1 | .23 | 63,000,000 | 2,100,000 | 10,200,000<br>L. A. 1,400,000 | 12,500,000 | |
| | 2 | .42 | 21,000,000<br>[a]89,000,000 | 2,000,000 | 63,000,000<br>L. A. 6,000,000 | 18,000,000 | Do. |
| 113 | 0 | .19 | 2,970,000 | 150,000 | 600,000 | 1,000,000 | |
| | 1 | .19 | 8,200,000 | 1,000,000 | 6,000,000<br>L. A. 300,000 | 1,500,000 | |
| | 2 | .29 | [a]92,000,000 | 1,000,000 | 67,000,000<br>L. A. 4,000,000 | 20,000,000 | |
| 115 | 0 | .19 | 2,060,000 | 40,000 | 2,500,000<br>L. A. 100,000 | 0 | No alkali formers in 1 : 100,000 dilution. |
| | 1 | .19 | 8,800,000 | 200,000 | 8,000,000<br>L. A. 300,000 | 2,000,000 | |
| | 2 | .29 | [a]76,000,000 | 3,000,000 | 58,000,000<br>L. A. 6,000,000 | 9,000,000 | |
| | 3 | .55 | ........ | ........ | ........ | ........ | Sour. |
| 117 | 0 | .22 | 210,000 | 10,000 | 340,000 | 50,000 | |
| | 1 | .25 | [a]32,000,000 | 3,000,000 | 16,000,000<br>L. A. 1,000,000 | 12,000,000 | |
| | 2 | .34 | [a]214,000,000 | 3,000,000 | 45,000,000<br>L. A. 12,000,000 | 154,000,000 | |
| 119 | 0 | .22 | [a]1,140,000 | 20,000 | 1,050,000<br>L. A. 10,000 | 60,000 | |
| | 1 | .25 | [a]6,000,000 | 1,000,000 | 5,000,000 | 0 | Gelatin dilution too high; no alkali formers in 1 : 1,000,000 dilution. |
| | 2 | .36 | [a]65,000,000 | 1,000,000 | 55,000,000<br>L. A. 1,000,000 | 8,000,000 | Slightly sour. |
| 121 | 0 | .19 | [a]1,410,000 | 310,000 | 450,000<br>L. A. 30,000 | 620,000 | |
| | 1 | .24 | [a]11,200,000 | 900,000 | 400,000<br>L. A. 900,000 | 8,000,000 | Sour on third day. |
| | | | | RAW MILK. | | | |
| 141 | 0 | ........ | 107,000,000 | 1,000,000 | 30,000,000<br>L. A. 6,000,000 | 8,000,000 | Samples 141 and 143 (inclusive). From stores, raw milk. |
| | 1 | 0.45 | 563,000,000 | 6,000,000 | ........ | 15,000,000 | Slightly sour; large number of lactic-acid bacteria; could not be counted. |

[a] In these cases gelatin was used instead of agar.

TABLE V.—*Raw and pasteurized milk at Boston, Mass., examined during November and December, 1908, and January, 1909—Milk held at 10° C. (50° F.)*—Continued.

RAW MILK—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 143 | 0 | ........ | 15,300,000 | 400,000 | 6,000,000<br>L. A. 500,000 | 1,600,000 | Could not estimate lactic acid and alkali forming bacteria; too many colonies. |
| | 1 | 0.33 | 195,000,000 | 2,500,000 | ........ | ........ | |
| | 2 | .45 | [a]440,000,000 | 20,000,000 | 420,000,000 | ........ | Slightly sour. |
| 145 | 0 | .18 | 160,000 | ........ | ........ | ........ | Gelatin plates liquefied. Samples of raw milk from dairy G, No. 145-185, inclusive. |
| | 1 | .19 | 4,460,000 | ........ | ........ | ........ | |
| | 2 | ........ | ........ | ........ | ........ | ........ | |
| | 3 | .36 | 763,500,000 | 50,000,000 | ........ | ........ | Gelatin partially liquefied. |
| | 4 | .52 | 1,450,000,000 | 20,000,000 | 700,000,000 | 200,000,000 | Slightly sour and slightly bitter. |
| 147 | 0 | .18 | 50,000 | ........ | ........ | ........ | Gelatin plates liquefied. |
| | 1 | .19 | 2,730,000 | 120,000 | ........ | 2,800,000 | Lactic-acid bacteria did not show. |
| | 2 | .19 | 69,000,000 | 3,000,000 | 20,000,000 | 30,000,000 | |
| | 3 | .42 | 910,000,000 | 2,500,000 | ........ | ........ | Slightly bitter; lactic acid and alkali forming bacteria were mostly acid colonies. |
| 149 | 0 | .20 | [a]7,100 | 2,600 | 600<br>L. A. 300 | 3,600 | |
| | 1 | .23 | [a]118,000 | 49,000 | L. A. 5,000 | 64,000 | |
| | 2 | .23 | [a]4,600,000 | 2,600,000 | 0 | 2,000,000 | No lactic-acid bacteria in 1 : 100,000 dilution. |
| | 3 | .24 | [a]27,000,000 | 7,000,000 | L. A. 5,000,000 | 15,000,000 | |
| | 4 | .28 | [a]74,000,000 | 8,000,000 | 15,000,000<br>L. A. 18,000,000 | 39,000,000 | |
| | 5 | .31 | [a]160,000,000 | 18,000,000 | 67,000,000<br>L. A. 55,000,000 | 20,000,000 | |
| 151 | 0 | .23 | [a]24,400 | 2,100 | 4,200<br>L. A. 200 | 17,900 | |
| | 1 | .23 | [a]2,100,000 | 100,000 | 1,400,000 | 600,000 | |
| | 2 | .23 | [a]9,200,000 | 700,000 | 2,000,000<br>L. A. 100,000 | 6,400,000 | |
| | 3 | .29 | [a]48,000,000 | 3,000,000 | 25,000,000 | 20,000,000 | |
| | 4 | .34 | [a]129,000,000 | 6,000,000 | 106,000,000 | 16,000,000 | |
| 153 | 0 | .20 | 234,000 | 1,000 | 255,000 | 5,000 | |
| | 1 | .22 | 13,000,000 | 100,000 | 2,800,000 | 600,000 | |
| | 2 | .26 | 25,000,000 | 1,000,000 | 18,000,000 | 11,000,000 | |
| | 3 | .29 | 590,000,000 | 6,000,000 | 162,000,000<br>L. A. 3,000,000 | 34,000,000 | |
| 155 | 0 | .21 | 405,000 | 40,000 | 400,000 | 50,000 | |
| | 1 | .23 | 8,500,000 | 1,800,000 | 2,500,000 | 3,700,000 | |
| | 2 | .23 | 151,000,000 | 9,000,000 | 22,000,000<br>L. A. 2,000,000 | 12,000,000 | |
| 157 | 0 | .22 | 212,000 | 3,000 | 171,000 | 7,000 | |
| | 1 | .22 | 32,900,000 | 200,000 | 9,500,000 | 500,000 | |
| 159 | 0 | .16 | 444,500 | ........ | ........ | ........ | Gelatin plates liquefied. |
| | 1 | .18 | 71,000,000 | 500,000 | 26,800,000 | 4,000,000 | |
| | 2 | .23 | 240,000,000 | 3,000,000 | 134,000,000<br>L. A. 1,000,000 | 20,000,000 | |
| | 3 | .38 | 641,000,000 | 12,000,000 | ........ | ........ | Slightly sour; lactic acid and alkali forming bacteria could not be counted. |
| 161 | 0 | .17 | 401,000 | ........ | ........ | ........ | Gelatin plates liquefied. |
| | 1 | .18 | [a]30,900,000 | 1,000,000 | 26,100,000<br>L. A. 200,000 | 3,600,000 | |
| | 2 | .29 | 370,000,000 | 5,000,000 | 90,000,000 | 200,000,000 | |
| | 3 | .47 | ........ | ........ | ........ | ........ | Sour. |

[a] In these cases gelatin was used instead of agar.

TABLE V.—*Raw and pasteurized milk at Boston, Mass., examined during November and December, 1908, and January, 1909—Milk held at 10° C. (50° F.)*—Continued.

RAW MILK—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 163 | 0 | 0.18 | 96,000,000 | 45,000 | .............. | .............. | Could not be counted. |
| | 1 | .23 | 218,000,000 | 5,000,000 | 100,000,000 | 40,000,000 | |
| | 2 | .75 | .............. | .............. | .............. | .............. | Sour. |
| 165 | 0 | .18 | 102,000,000 | .............. | .............. | .............. | Gelatin plates could not be counted. |
| | 1 | .22 | 119,000,000 | 15,000,000 | (a) | (a) | Sour. |
| 167 | 0 | .15 | 2,900,000 | 150,000 | .............. | .............. | A few acid and large number of alkali colonies. Could not estimate. |
| | 1 | .16 | 56,000,000 | 430,000 | 41,000,000 | 17,200,000 | |
| | 2 | .25 | 284,000,000 | 10,000,000 | 210,000,000 | 45,000,000 | |
| | 3 | .45 | 731,000,000 | 0 | 600,000,000<br>L. A. 10,000,000 | 50,000,000 | |
| | 4 | .74 | .............. | .............. | .............. | .............. | |
| 169 | 0 | .16 | 3,180,000 | 130,000 | (a) | (a) | |
| | 1 | .17 | 150,000,000 | .............. | .............. | .............. | Gelatin plates liquefied. |
| | 2 | .26 | 360,000,000 | 5,000,000 | 270,000,000 | 38,000,000 | |
| | 3 | .47 | 681,000,000 | 10,000,000 | 770,000,000 | 30,000,000 | |
| 170 | 0 | .17 | 91,000 | 30,000 | 9,000 | .............. | Numerous alkali colonies grouped together. |
| | 1 | .17 | 3,170,000 | 900,000 | 1,200,000 | 1,800,000 | |
| | 2 | .17 | 37,700,000 | 2,600,000 | 9,900,000<br>L. A. 200,000 | 14,500,000 | |
| | 3 | .27 | 298,000,000 | 4,000,000 | 167,000,000 | 30,000,000 | |
| 171 | 0 | .16 | 102,000 | .............. | .............. | .............. | Plates liquefied. |
| | 1 | .16 | 4,500,000 | 300,000 | 700,000 | 3,390,000 | |
| | 2 | .17 | 16,800,000 | 1,700,000 | 14,600,000<br>L. A. 500,000 | 20,900,000 | |
| | 3 | .33 | 545,000,000 | .............. | 180,000,000 | .............. | Gelatin contaminated; lactic - acid bacteria determined on agar. |
| 173 | 0 | .14 | 128,000 | 60,000 | 30,000 | 30,000 | |
| | 1 | .14 | 2,040,000 | 250,000 | 560,000<br>L. A. 30,000 | 960,000 | |
| | 2 | .15 | 59,000,000 | 1,700,000 | 28,300,000 | 15,500,000 | |
| | 3 | .25 | 620,000,000 | 10,000,000 | 250,000,000 | 70,000,000 | |
| | 4 | .40 | 635,000,000 | 10,000,000 | 62,000,000 | 60,000,000 | Slightly sour. |
| 175 | 0 | .14 | 133,000 | 30,000 | 50,000 | 50,000 | |
| | 1 | .15 | 2,170,000 | 300,000 | 820,000 | 880,000 | |
| | 2 | .17 | 107,000,000 | .............. | 14,000,000<br>(Agar.) | .............. | Gelatin liquefied. |
| | 3 | .26 | 420,000,000 | .............. | .............. | .............. | Do. |
| | 4 | .42 | 663,000,000 | 6,000,000 | 70,000,000 | 29,000,000 | Slightly sour. |
| 177 | 0 | .14 | 894,000 | 50,000 | 210,000<br>L. A. 20,000 | 830,000 | |
| | 1 | .16 | 30,900,000 | .............. | 5,600,000<br>(Agar.) | .............. | Gelatin liquefied; lactic-acid bacteria determined on agar. |
| | 2 | .20 | 212,000,000 | 2,000,000 | 34,000,000 | 129,000,000 | |
| | 3 | .30 | 560,000,000 | 80,000,000 | 200,000,000 | 50,000,000 | |
| | 4 | .63 | .............. | .............. | .............. | .............. | Sour. |
| 179 | 0 | .14 | 583,000 | .............. | .............. | .............. | Gelatin liquefied. |
| | 1 | .15 | 50,000,000 | .............. | .............. | .............. | Do. |
| | 2 | .18 | 130,000,000 | 20,000,000 | 60,000,000 | 70,000,000 | |
| | 3 | .31 | [b]360,000,000 | 19,000,000 | 240,000,000<br>L. A. 11,000,000 | 90,000,000 | |
| 181 | 0 | .14 | 390,000 | 20,000 | 220,000 | 70,000 | |
| | 1 | .15 | 19,000,000 | 1,200,000 | 20,000,000 | 4,000,000 | |
| | 2 | .19 | [b]185,000,000 | 5,000,000 | 67,000,000 | 113,000,000 | |
| | 3 | .32 | [b]320,000,000 | 5,000,000 | 275,000,000 | 40,000,000 | |

[a] Not estimated.

[b] In these cases gelatin was used instead of agar.

TABLE V.—*Raw and pasteurized milk at Boston, Mass., examined during November and December, 1908, and January, 1909—Milk held at 10° C. (50° F.)*—Continued.

RAW MILK—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 183 | 0 | 0.15 | 580,000 | ............ | ............ | ............ | Gelatin liquefied. |
| | 1 | .17 | [a]35,600,000 | 1,500,000 | 24,000,000<br>L. A. 1,300,000 | 8,800,000 | |
| | 2 | .36 | [a]336,000,000 | 2,000,000 | 306,000,000<br>L. A. 3,000,000 | 25,000,000 | |
| 185 | 0 | .15 | [a]128,000 | 4,000 | 109,000<br>L. A. 8,000 | 12,000 | |
| | 1 | .15 | [a]18,000,000 | 700,000 | 11,100,000<br>L. A. 1,400,000 | 4,800,000 | |
| | 2 | ........ | ............ | ............ | ............ | ............ | |
| | 3 | .44 | ............ | ............ | ............ | ............ | Slightly sour. |

[a] In these cases gelatin was used instead of agar.

TABLE VI.—*Raw and pasteurized milk at Boston, Mass.—Examination of winter milk held at room temperature, 21.1° C. (70° F.).*

PASTEURIZED MILK.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 46 | 0 | ........ | 21,200 | 4,000 | 15,400 | 5,500 | From dairy B, No. 46 to 64 (inclusive). Pasteurized (140-150° F.) 60-65.6° C. "flash" process. |
| | 1 | 0.22 | 44,000,000 | 4,800,000 | 30,500,000<br>L. A. 800,000 | 7,900,000 | |
| 48 | 0 | .18 | 34,000 | 4,600 | 1,200<br>L. A. 200 | 10,000 | |
| | 1 | 27 | 217,000,000 | 7,000,000 | 200,000,000 | 33,000.000 | |
| 50 | 0 | .19 | 41,200 | 3,000 | 32,000 | 10.000 | |
| | 1 | .24 | 302,000,000 | 8,000,000 | 207,000,000<br>L. A. 4,000,000 | 9,000,000 | |
| 52 | 0 | .20 | 230,000 | 23,000 | 39,000<br>L. A. 79,000 | 60,000 | |
| | 1 | .23 | ............ | ............ | ............ | ............ | |
| 54 | 0 | .19 | 145,000 | 9,000 | 60,000 | 50,000 | |
| | 1 | .24 | 576,000,000 | 30,000,000 | 280,000,000 | 120,000,000 | |
| 56 | 0 | .24 | 31,400 | 4,000 | 36,000<br>L. A. 11,000 | 8,000 | |
| | 1 | .39 | 408,000,000 | 9,000,000 | 370,000,000<br>L. A. 26,000,000 | 19,000,000 | |
| 58 | 0 | .34 | 206,000 | 19,000 | 100,000<br>L. A. 11,000 | 6,000 | |
| | 1 | .71 | 549,000,000 | 2,000,000 | 480,000,000<br>L. A. 58,000,000 | 0 | Sour. |
| 60 | 0 | .32 | 223,000 | 12,000 | 200,000<br>L. A. 500,000 | 45,000 | |
| | 1 | .58 | 273,000,000 | 1,000,000 | 253,000,000<br>L. A. 24,000,000 | 117.000,000 | Slightly sour. |
| 62 | 0 | .18 | 255,000 | 19,000 | 62,000<br>L. A. 34,000 | 40,000 | |
| | 1 | .34 | 190,000,000 | 12,000,000 | 72,000,000<br>L. A. 21,000,000 | 125,000,000 | |
| 64 | 0 | .18 | 193,000 | 5,000 | 140,000<br>L. A. 19,000 | 26,000 | |
| | 1 | .27 | 295,000,000 | 4,000,000 | 286,000,000<br>L. A. 14,000,000 | 96,000,000 | |

TABLE VI.—*Raw and pasteurized milk at Boston, Mass.—Examination of winter milk held at room temperature, 21.1° C. (70° F.)*—Continued.

PASTEURIZED MILK—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 66 | 0 | 0.25 | 14,500,000 | ([a]) | [b] 6,700 | ([a]) | From dairy A, No. 66 to 88 (inclusive. Pasteurized (140–150° F.) 60–65.6° C., "holder" process. |
| | 1 | .29 | 70,000,000 | 11,000,000 | 30,000,000<br>L. A. 4,000,000 | 33,000.000 | |
| 68 | 0 | .27 | 63,000 | 8,000 | 40,000 | 0 | |
| | 1 | .72 | 380,000,000 | 20,000,000 | 200,600,000<br>L. A. 4,000,000 | 29,000,000 | Sour. |
| 70 | 0 | .27 | 61,000 | 1,000 | 27,000 | ............. | Acid or alkali. |
| | 1 | ........ | 143,000,000 | 8,000,000 | 107,000,000<br>L. A. 3,000,000 | 33,000,000 | |
| 72 | 0 | .18 | 51,800 | 2,000 | 29,000 | 19,200 | |
| | 1 | .22 | 16,000,000 | 5,000,000 | 19,000,000 | 4,000,000 | |
| 74 | 0 | .16 | 28,300 | 2,400 | 20,000 | 9,200 | |
| | 1 | .18 | 10,200,000 | 13,000,000 | 11,000,000 | 17,000,000 | |
| 76 | 0 | .18 | 172,000 | 23,000 | 176,000 | 13,000 | |
| | 1 | .27 | 276,000,000 | 5,000,000 | 250,000,000 | 44,000,000 | |
| 78 | 0 | .18 | 78,600 | 1,400 | 3,500 | 61,000 | |
| | 1 | .19 | 16,900,000 | 2,000,000 | 14,000,000 | 19,000,000 | |
| 80 | 0 | .18 | 63,100 | 1,000 | 30,000<br>L. A. 6,000 | 15,000 | |
| | 1 | .27 | 17,000,000 | 300,000 | 8,000,000<br>L. A. 100,000 | 2,800,000 | |
| 82 | 0 | .18 | 20,200 | 100 | 13,000 | 25,000 | |
| | 1 | .19 | 72,000,000 | 10,000,000 | 20,000,000 | 10,000,000 | Count not accurate; dilution too high. |
| | 2 | .90 | ................ | ............. | ................ | ............. | Sour, curdled. |
| 84 | 0 | .18 | 46,000 | 300 | 30,000 | ............. | Acid or alkali. |
| | 1 | .18 | 24,000,000 | ............. | ................ | ............. | Gelatin liquefied. |
| 86 | 0 | .18 | 6,900 | ............. | ................ | ............. | Do. |
| | 1 | .18 | 14,800,000 | ............. | ................ | ............. | Do. |
| | 2 | .52 | ................ | ............. | ................ | ............. | Sour. |
| 88 | 0 | .18 | 86,200 | 100 | 83,000 | ............. | |
| | 1 | .18 | 150,000,000 | ............. | ................ | ............. | Gelatin liquefied. |
| | 2 | .89 | ................ | ............. | ................ | ............. | Sour, curdled. |
| 92 | 0 | .20 | 79,640,000 | ............. | ................ | ............. | Gelatin liquefied. From dairy C, No. 92 to 102; also 122. |
| | 1 | .58 | 120,960,000,000 | ............. | ................ | ............. | Gelatin liquefied; sour. |
| | 2 | 1.03 | ................ | ............. | ................ | ............. | Mostly acid colonies, pasteurized, "flash" process, 160° F. (76.7° C.). |
| 94 | 0 | .20 | 3,700,000 | 800,000 | 2,500,000 | 0 | |
| | 1 | .35 | 7,040,000,000 | 9,000,000 | 93,000,000<br>L. A. 7,000,000 | 95,000,000 | Slightly sour. |
| 96 | 0 | .28 | 16,900,000 | 250,000 | 3,000,000 | 5,000,000 | |
| | 1 | .94 | ................ | ............. | ................ | ............. | Curdled, gas. |
| 98 | 0 | .24 | 4,300,000 | 60,000 | 0 | 80,000 | Plates were partially liquefied. |
| | 1 | .56 | 1,088,000,000 | 3,000,000 | [a] 3,500,000<br>900,000,000<br>L. A. 30,000,000 | 60,000,000 | Slightly sour. |
| 100 | 0 | .24 | 1,560,000 | ............. | ................ | ............. | |
| | 1 | .71 | ................ | ............. | ................ | ............. | |

[a] Plate liquefied.

[b] On agar.

**TABLE VI.**—*Raw and pasteurized milk at Boston, Mass.—Examination of winter milk held at room temperature, 21.1° C. (70° F.)*—Continued.

PASTEURIZED MILK—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 102 | 0 | 0.18 | 1,400,000 | 70,000 | 700,000 | 100,000 | |
| | 1 | .58 | 830,000,000 | 12,000,000 | ... | ... | Gelatin liquefied; slightly sour; could not be used. |
| 122 | 0 | .19 | [a]4,200,000 | 100,000 | 2,500,000<br>L. A. 100,000 | 1,500,000 | |
| | 1 | .40 | 77,000,000 | 7,000,000 | 50,000,000<br>L. A. 2,000,000 | 18,000,000 | |

RAW MILK.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 142 | 0 | ... | 107,000,000 | ... | ... | ... | Raw milk from stores, No. 142 to 144. |
| | 1 | 0.42 | 573,000,000 | 3,000,000 | [b]500,000,000<br>L. A. 37,000,000 | 4,000,000 | |
| | 2 | .55 | ... | ... | ... | ... | Sour. |
| 144 | 0 | ... | 15,300,000 | ... | ... | ... | |
| | 1 | .37 | 305,000,000 | 3,000.000 | ... | ... | Gelatin liquefied. |
| | 2 | .81 | ... | ... | ... | ... | Sour. |
| 146 | 0 | .18 | 302,000 | | | | Gelatin liquefied. Raw milk from dairy G, No. 146 to 152. |
| | 1 | .20 | 81,800,000 | ... | ... | ... | |
| | 2 | ... | ... | | | | |
| 148 | 0 | .18 | 50,300 | ... | ... | ... | Gelatin liquefied. |
| | 1 | .19 | 34,900,000 | 1,000,000 | ... | ... | Plates badly liquefied; few acid and numerous alkali. |
| | 2 | .90 | ... | ... | ... | ... | Sour, curdled. |
| 150 | 0 | .20 | 18,000 | 1,700 | 500<br>L. A. 900 | 2,700 | |
| | 1 | .23 | [a]105,000,000 | 5,000,000 | 80,000,000 | 20,000,000 | |
| | 2 | ... | ... | ... | ... | ... | Do. |
| 152 | 0 | .22 | 83,500 | 4,100 | 76.800 | 2,600 | |
| | 1 | .81 | ... | ... | ... | ... | Do. |

[a] Gelatin.
[b] Approximate.

**TABLE VII.**—*Raw and pasteurized milk at Boston, Mass.—Examination of summer milk held at 10° C. (50° F.).*[a]

PASTEURIZED MILK.

| Sample No. | Age of milk in days. | Acidity in per centage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 271 | 0 | 0.18 | 15,500,000 | 1,900,000 | 83,200,000 | | Mostly lactic forms. Samples Nos. 271-283 from dairy A. |
| | 1 | .31 | 100,000,000 | 3,000,000 | 115,000,000<br>L. A.[b] 26,000,000 | 9,000,000 | |
| | 2 | .78 | ... | ... | ... | ... | Curdled. |

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[a] 10° C. (50° F.) is used to show that milk was held in the refrigerator. During this series in June the temperature of the refrigerator probably ranged between 10° C. (50° F.) and 15° C. (59° F.).

[b] L. A. means B. lactis aerogenes. The colonies growing on gelatin plates which looked like typical colonies of B. lactis aerogenes were included in the counts.

**Table** VII.—*Raw and pasteurized milk at Boston, Mass.—Examination of summer milk held at 10° C. (50° F.)*—Continued.

PASTEURIZED MILK—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 272 | 0 | 0.15 | 140,000 | 5,600 | 6,000<br>L. A. 62,000 | 372,000 | |
| | 1 | .15 | 9,600,000 | 220,000 | 70,000<br>L. A. 750,000 | 1,700,000 | |
| | 2 | .22 | 200,000,000 | 8,000,000 | 98,000,000<br>L. A. 88,000,000 | 20,000,000 | Slightly sour; cheesy. |
| 273 | 0 | .15 | 42,000 | 6,000 | 1,000<br>L. A. 2,000 | 88,000 | |
| | 1 | .15 | 20,000,000 | 3,600,000 | 16,500,000<br>L. A. 17,400,000 | 18,700,000 | |
| | 2 | .24 | 247,000,000 | 2,000,000 | 206,000,000<br>L. A. 107,000,000 | 0 | Slightly sour. |
| 274 | 0 | .15 | 580,000 | 70,000 | 434,000<br>L. A. 50,000 | 230,000 | |
| | 1 | .15 | 25,700,000 | 6,000,000 | 7,000,000<br>L. A. 11,000,000 | 20,000,000 | |
| 275 | 0 | .15 | 24,000 | 6,000 | 1,000<br>L. A. 1,000 | 19,000 | |
| | 1 | .15 | 2,490,000 | 1,100,000 | 0 | 1,600,000 | |
| | 2 | .15 | 19,000,000 | 2,000,000 | 600,000<br>L. A. 6,800,000 | 12,600,000 | |
| | 3 | .16 | 71,000,000 | 5,000,000 | 4,000,000<br>L. A. 28,000,000 | 40,000,000 | Old taste; would not be used. |
| 276 | 0 | .15 | 12,000 | ........ | ........ | ........ | No counts. |
| | 1 | .15 | 170,000 | 20,000 | 0 | 270,000 | |
| | 2 | .15 | 6,000,000 | 2,000,000 | 1,000,000<br>L. A. 1,000,000 | 1,000,000 | |
| | 3 | ........ | ........ | ........ | ........ | ........ | |
| | 4 | .47 | ........ | ........ | ........ | ........ | Sour and cheesy. |
| 277 | 0 | .15 | 197,000 | 21,000 | 17,000 | 57,000 | |
| | 1 | .15 | 16,300,000 | 2,700,000 | 1,800,000 | 17,800,000 | |
| | 2 | ........ | ........ | ........ | ........ | ........ | |
| | 3 | 1.25 | ........ | ........ | ........ | ........ | Sour; curdled. |
| 278 | 0 | .14 | 20,000 | 1,000 | 7,000<br>L. A. 1,000 | 17,000 | |
| | 1 | ........ | ........ | ........ | ........ | ........ | |
| | 2 | .27 | 183,000,000 | 8,000,000 | 226,000,000<br>L. A. 23,000,000 | 67,000,000 | |
| | 3 | .74 | ........ | ........ | ........ | ........ | Do. |
| 279 | 0 | .15 | 194,000 | 45,000 | 32,000<br>L. A. 16,000 | 193,000 | |
| | 1 | .15 | 43,000,000 | 8,000,000 | 6,000,000<br>L. A. 11,000,000 | 65,000,000 | |
| | 2 | .23 | 333,000,000 | 2,000,000 | 75,000,000<br>L. A. 53,000,000 | 31,000,000 | Slightly sour. |
| 280 | 0 | .15 | 38,000 | ........ | ........ | ........ | No elating counts. |
| | 1 | .15 | 27,300,000 | 200,000 | 400,000<br>L. A. 8,800,000 | 20,000,000 | |
| | 2 | .15 | 92,000,000 | 600,000 | ........ | ........ | Large number of acid colonies; plate could not be counted; slightly old taste. |
| | 3 | .54 | ........ | ........ | ........ | ........ | Slightly sour; cheesy. |
| 281 | 0 | .15 | 144,000 | 4,000 | L. A. 64,000 | 75,000 | |
| | 1 | .15 | 15,500,000 | 500,000 | L. A. 1,800,000 | 8,500,000 | |
| | 2 | .19 | 166,000,000 | 700,000 | L. A. 100,000 | 30,000 | |
| | 3 | .28 | ........ | ........ | ........ | ........ | Slightly old taste. |
| 282 | 0 | .15 | 321,000 | ........ | ........ | ........ | Gelatin liquefied. |
| | 1 | .15 | 21,200,000 | ........ | ........ | ........ | Do. |
| | 2 | ........ | ........ | ........ | ........ | ........ | |
| | 3 | .27 | ........ | ........ | ........ | ........ | Slightly sour. |
| 283 | 0 | .15 | 20,000 | ........ | ........ | ........ | Gelatin liquefied. |
| | 1 | ........ | ........ | ........ | ........ | ........ | |
| | 2 | .15 | 86,000,000 | ........ | ........ | ........ | Do. |
| | 3 | .23 | 294,000,000 | ........ | ........ | ........ | Gelatin liquefied; slightly sour and cheesy. |

TABLE VII.—*Raw and pasteurized milk at Boston, Mass.—Examination of summer milk held at 10° C. (50° F.)*—Continued.

RAW MILK.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 284 | 0 | 0.17 | [a] 2,570,000 | 200,000 | 700,000<br>L. A. 170,000 | 1,500,000 | Raw milk from stores, Nos. 284 to 293. |
| | 1 | .20 | [a] 95,000,000 | 6,000,000 | 25,000,000<br>L. A. 2,000,000 | 62,000,000 | |
| | 2 | .9 | | | | | Curdled. |
| 285 | 0 | .17 | [a] 13,900,000 | 1,500,000 | 10,000,000<br>L. A. 900,000 | 1,500,000 | |
| | 1 | .25 | [a] 85,000,000 | 1,000,000 | 57,000,000<br>L. A. 11,000,000 | 16,000,000 | |
| | 2 | .72 | | | | | Partly curdled. |
| 286 | 0 | .17 | [a] 5,000,000 | 0 | 1,000,000 | 4,000,000 | |
| | 1 | .39 | [a] 238,000,000 | 6,000,000 | 172,000,000<br>L. A. 10,000,000 | 50,000,000 | |
| | 2 | .68 | | | | | Sour. |
| 287 | 0 | .17 | [a] 9,700,000 | 300,000 | 6,500,000<br>L. A. 500,000 | 2,400,000 | |
| | 1 | .33 | [a] 164,000,000 | 11,000,000 | 53,000,000<br>L. A. 26,000,000 | 74,000,000 | |
| | | .60 | | | | | Sour. |
| 288 | 0 | .18 | 10,000,000 | 3,000,000 | 18,000,000<br>L. A. 1,000,000 | 6,200,000 | |
| | 1 | .34 | 568,000,000 | 0 | 500,000,000<br>L. A. 4,000,000 | 1,000,000 | |
| | 2 | .92 | | | | | Curdled. |
| 289 | 0 | .24 | 50,100,000 | 400,000 | 40,000,000<br>L. A. 1,200,000 | 1,500,000 | |
| | 1 | .36 | 299,000,000 | 1,000,000 | 4,000,000<br>L.A. 195,000,000 | 0 | Slightly sour. |
| 290 | 0 | .16 | 7,000,000 | 300,000 | 6,700,000<br>L. A. 600,000 | 1,200,000 | |
| | 1 | .19 | 135,000,000 | 5,000,000 | 68,000,000<br>L. A. 17,000,000 | 16,000,000 | |
| 291 | 0 | .16 | 7,700,000 | 600,000 | 8,700,000<br>L. A. 900,000 | 1,200,000 | |
| | 1 | .20 | 162,000,000 | 1,000,000 | 104,000,000<br>L. A. 11,000,000 | 8,000,000 | |
| 292 | 0 | .16 | 4,430,000 | 2,100,000 | 7,100,000 | 2,000,000 | |
| | 1 | .22 | 144,000,000 | 10,000,000 | 86,000,000<br>L. A. 14,000,000 | 67,000,000 | |
| | 2 | .22 | 254,000,000 | 4,000,000 | 141,000,000<br>L. A. 13,000,000 | 0 | Old taste. |
| 293 | 0 | .16 | 5,400,000 | 1,000,000 | 900,000<br>L. A. 500,000 | 2,100,000 | |
| | 1 | .19 | 91,000,000 | 8,000,000 | 21,000,000<br>L. A. 3,000,000 | 47,000,000 | |
| | 2 | .35 | 162,000,000 | 32,000,000 | 61,000,000<br>L. A. 24,000,000 | 342,000.000 | |
| | 3 | | | | | | |
| | 4 | .91 | | | | | Curdled. |
| 294 | 0 | .15 | 3,900,000 | 200,000 | 620,000<br>L. A. 140,000 | 940,000 | Raw milk from dairy E, Nos. 294-299. |
| | 1 | .15 | 21,300,000 | 800,000 | 5,600,000<br>L. A. 2,100,000 | 10,000,000 | |
| | 2 | | | | | | |
| | 3 | 1.5 | | | | | Curdled; gas. |
| 295 | 0 | .15 | 3,600,000 | 140,000 | 1,800,000<br>L. A. 230,000 | 880,000 | |
| | 1 | | | | | | |
| | 2 | .81 | | | | | Curdled. |

[a] Gelatin.

TABLE VII.—*Raw and pasteurized milk at Boston, Mass.—Examination of summer milk held at 10° C. (50° F.)*—Continued.

RAW MILK—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 297 | 0 | 0.17 | 18,200,000 | | | | Gelatin liquefied. |
| | 1 | .18 | 229,000,000 | 70,000,000 | 5,000,000 | 160,000,000 | |
| | 2 | .39 | | | | | Slightly sour. |
| 298 | 0 | .15 | 4,400,000 | 460,000 | 1,100,000<br>L. A. 40,000 | 1,800,000 | |
| | 1 | .18 | 125,000,000 | 0 | 50,000,000<br>L. A. 10,000,000 | 20,000,000 | |
| | 2 | .57 | 1,100,000,000 | | | | Gelatin liquefied; milk sour. |
| 299 | 0 | .15 | 7,700,000 | 100,000 | 600,000 | 5,000,000 | |
| | 1 | .23 | 268,000,000 | (a) 0 | 120,000,000 | 80,000,000 | |
| | 2 | | | | | | |
| | 3 | .64 | | | | | Curdled; gas. |
| 300 | 0 | .15 | 29,200,000 | | | | Gelatin liquefied; raw milk from dairy F. Nos. 300 to 305. |
| | 1 | | | | | | |
| | 2 | .43 | 304,000,000 | | | | Gelatin liquefied. |
| | 3 | .90 | | | | | Curdled. |
| 301 | 0 | .16 | 15,000,000 | | | | Gelatin liquefied. |
| | 1 | .29 | 136,000,000 | | | | Do. |
| | 2 | .76 | | | | | Sour gas; slightly putrid taste. |
| 302 | 0 | .16 | 76,800,000 | | | | Gelatin liquefied. |
| | 1 | .67 | | | | | Sour; gas. |
| 303 | 0 | .20 | 43,100,000 | | | | Gelatin liquefied. |
| | 1 | .54 | 300,000,000 | | | | Do. |
| | 2 | .94 | | | | | Curdled. |
| 304 | 0 | .18 | 133,000,000 | | | | Gelatin liquefied. |
| | 1 | .66 | | | | | Sour. |
| 305 | 0 | .18 | 1,100,000 | | | | Gelatin liquefied. |
| | 1 | .27 | 192,000,000 | | | | Do. |

RAW AND PASTEURIZED MILK.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| [b]306 | 0 | 0.15 | 1,760,000 | 220,000 | 560,000 | 330,000 | From dairy B, pasteurized "flash" process, 60°-65.6° C. (140°-150° F.), samples Nos. 306-323, inclusive. |
| | 1 | .15 | 3,390,000 | 400,000 | 4,400,000 | 1,000,000 | |
| | 2 | .30 | 75,000,000 | 3,000,000 | 34,000,000<br>L. A. 1,000,000 | 50,000,000 | Slightly sour. |
| | 3 | .42 | | | | | Sour. |
| [b]307 | 0 | .15 | 1,450,000 | 100,000 | 900,000<br>L. A. 100,000 | 300,000 | |
| | 1 | .15 | 9,900,000 | 100,000 | 8,000,000 | 1,000,000 | |
| | 2 | .27 | 328,000,000 | 4,000,000 | 45,000,000 | 240,000,000 | |
| | 3 | .43 | | | | | Slightly sour. |
| [c]308 | 0 | .16 | 14,500,000 | 500,000 | 2,600,000<br>L. A. 1,000,000 | 3,000,000 | |
| | 1 | .19 | 26,000,000 | 6,000,000 | 37,000,000<br>L. A. 4,000,000 | 20,000,000 | |
| | 2 | .64 | | | | | Sour. |
| [b]309 | 0 | .15 | 6,300,000 | 100,000 | 3,000,000 | 1,700,000 | |
| | 1 | .16 | 108,000,000 | 3,000,000 | 3,000,000 | 32,000,000 | |
| | 2 | | | | | | |
| | 3 | .45 | 856,000,000 | | | | Slightly sour. |

[a] Liquid in 1,000,000 dilutions. [b] Pasteurized. [c] Raw.

TABLE VII.—*Raw and pasteurized milk at Boston, Mass.—Examination of summer milk held at 10° C. (50° F.)*—Continued.

RAW AND PASTEURIZED MILK—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| [a] 310 | 0 | 0.15 | 1,210,000 | | | | Gelatin liquefied. |
| | 1 | | | | | | |
| | 2 | .26 | 205,000,000 | | | | |
| | 3 | .82 | | | | | Sour. |
| [b] 311 | 0 | .15 | 23,600,000 | 700,000 | 5,800,000<br>L. A. 1,300,000 | 7,400,000 | |
| | 1 | | | | | | |
| | 2 | .42 | 292,000,000 | | | | Slightly sour. |
| | 3 | .78 | | | | | Curdled. |
| [a] 312 | 0 | .15 | 215,000 | | | | |
| | 1 | .19 | 91,000,000 | | | | |
| | 2 | .74 | | | | | Sour. |
| [b] 313 | 0 | .15 | 8,900,000 | | | | |
| | 1 | .25 | 139,000,000 | | | | |
| | 2 | .64 | | | | | Do. |
| [a] 314 | 0 | .15 | 16,900,000 | | | | |
| | 1 | .33 | 42,000,000 | | | | |
| | 2 | .72 | | | | | Do. |
| [b] 315 | 0 | .24 | 48,000,000 | 1,400,000 | | | |
| | 1 | .74 | | | | | Do. |
| [a] 316 | 0 | .15 | 4,095,000 | | | | |
| | 1 | .22 | 151,000,000 | | | | |
| | 2 | 1.02 | | | | | |
| [b] 317 | 0 | .18 | 12,600,000 | | | | |
| | 1 | .54 | 280,000,000 | | | | Slightly sour. |
| | 2 | .90 | | | | | Curdled. |
| [a] 318 | 0 | .15 | 1,940,000 | | | | |
| | 1 | .20 | 130,000,000 | | | | |
| | 2 | .65 | | | | | Sour. |
| [b] 319 | 0 | .18 | 32,000,000 | | | | |
| | 1 | .38 | 60,000,000 | | | | Do. |
| | | .59 | | | | | |
| [a] 320 | 0 | .15 | 4,100,000 | | | | |
| | 1 | .36 | 361,000,000 | | | | |
| 321 | 0 | .18 | 79,000,000 | | | | |
| | 1 | .90 | | | | | Curdled. |
| [a] 322 | 0 | .15 | 31,200,000 | | | | |
| [b] 323 | 0 | .18 | 111,000,000 | | | | |

[a] Pasteurized. [b] Raw.

In the above table of raw and pasteurized milk from dairy B the samples of milk were taken from the dairy at the same time they would have been delivered to the public and when first examined were 24 hours old. When two samples such as pasteurized 307 and raw 308 are placed together, it shows that the samples were taken the same day, before and after pasteurization at the dairy and then allowed to remain in the dairy refrigerator until the next day in order to duplicate commercial conditions.

TABLE VIII.—*Raw and pasteurized milk at Boston, Mass.—Total bacterial counts and group percentages—Milk held at 10° C. (50° F.).*

PASTEURIZED MILK—DAIRY B.

| Sample No. | Age of milk in days. | Total bacteria per c. c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|
| 45 | 0 | 36,400 | 13.46 | 61.53 | 24.99 |
|  | 1 | 142,000 | 8.45 | 61.26 | 30.28 |
| 47 | 0 | 28,300 | 16.96 | 53.71 | 29.32 |
| 49 | 0 | 40,700 | 8.35 | 82.55 | 9.09 |
|  | 1 | 260,000 | 11.53 | 50.00 | 38.46 |
| 51 | 0 | 205,000 | 3.414 | 62.43 | 34.14 |
|  | 1 | 2,100,000 | 4.76 | 66.66 | 28.57 |
| 53 | 0 | 124,000 | 4.83 | 70.96 | 24.19 |
| 55 | 0 | 117,000 | 10.25 | 55.55 | 34.18 |
|  | 1 | 280,000 | 53.57 | 21.42 | 25.00 |
| 57 | 0 | 220,000 | 4.54 | 81.81 | 13.63 |
|  | 1 | 7,800,000 | 6.41 | 60.25 | 33.33 |
| 59 | 0 | 529,000 | 8.50 | 78.26 | 13.23 |
|  | 1 | 7,820,000 | 4.21 | 90.02 | 5.75 |
| 61 | 0 | 214,000 | 32.71 | 43.92 | 23.36 |
|  | 1 | 3,500,000 | 22.85 | 51.42 | 25.71 |
| 63 | 0 | 204,000 | 18.62 | 34.31 | 47.05 |
|  | 1 | 950,000 | 36.84 | 21.05 | 42.10 |

PASTEURIZED MILK—DAIRY A.

| Sample No. | Age of milk in days. | Total bacteria per c. c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|
| 67 | 0 | 116,000 | 5.17 | 92.24 | 2.58 |
|  | 1 | 18,700,000 | 7.48 | 58.82 | 33.68 |
| 69 | 0 | 45,300 | 5.96 | 5.73 | 88.30 |
|  | 1 | 790,000 | 11.39 | 1.26 | 87.34 |
| 71 | 0 | 48,700 | 6.16 | 69.81 | 24.02 |
|  | 1 | 430,000 | 23.25 | 58.13 | 18.60 |
| 73 | 0 | 34,700 | 2.88 | 52.73 | 44.38 |
|  | 1 | 1,970,000 | 6.09 | ........ | 93.90 |
| 75 | 0 | 175,000 | 8.57 | 82.85 | 8.57 |
|  | 1 | 1,140,000 | 8.77 | 57.89 | 33.33 |
| 77 | 0 | 56,200 | 4.98 | 6.04 | 88.96 |
|  | 1 | 1,400,000 | 7.14 | ........ | 92.85 |
| 79 | 0 | 43,600 | 1.37 | 75.68 | 22.93 |
|  | 1 | 30,000 | ........ | 100.00 | ....... |
| 81 | 0 | 41,000 | ........ | 87.80 | 12.19 |
| 83 | 0 | 24,000 | 4.16 | 91.66 | 4.16 |
| 85 | 0 | 9,000 | ........ | 66.66 | 33.33 |
| 89 | 0 | ........... | ........ | ........ | ....... |
|  | 1 | 132,000 | 15.90 | 34.09 | 50.00 |
|  | 2 | ........... | ........ | ........ | ....... |
|  | 3 | 26,100,000 | 10.34 | 13.02 | 76.62 |
|  | 4 | 300,000,000 | 2.00 | 76.66 | 21.33 |
| 123 | 0 | ........... | ........ | ........ | ....... |
|  | 1 | ........... | ........ | ........ | ....... |
|  | 2 | ........... | ........ | ........ | ....... |
|  | 3 | 4,400,000 | 77.27 | 22.72 | ....... |
| 125 | 0 | ........... | ........ | ........ | ....... |
|  | 1 | 39,700,000 | 1.51 | 73.55 | 24.93 |
|  | 2 | 97,000,000 | 9.27 | 75.25 | 15.46 |
| 129 | 0 | 9,000 | 22.22 | ........ | 77.77 |
|  | 1 | 2,400,000 | 29.16 | ........ | 70.83 |
|  | 2 | 35,000,000 | 2.85 | 28.57 | 68.57 |
| 131 | 0 | 35,000 | 22.85 | 2.85 | 74.28 |
|  | 1 | 2,400,000 | 8.33 | ........ | 91.66 |
|  | 2 | ........... | ........ | ........ | ....... |
|  | 3 | 77,000,000 | 7.79 | 28.57 | 63.63 |
| 133 | 0 | 12,000 | 12.50 | 4.16 | 83.33 |
|  | 1 | ........... | ........ | ........ | ....... |
|  | 2 | 14,400,000 | 9.72 | 1.38 | 88.88 |
|  | 3 | 54,000,000 | 9.25 | 29.62 | 61.11 |

TABLE VIII.—*Raw and pasteurized milk at Boston, Mass.—Total bacterial counts and group percentages—Milk held at 10° C. (50° F.)*—Continued.

### PASTEURIZED MILK—DAIRY C.

| Sample No. | Age of milk in days. | Total bacteria per c. c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|
| 93 | 0 | 3,300,000 | 24.24 | 75.75 | ....... |
| | 1 | 10,600,000 | 18.86 | 9.43 | 71.69 |
| 95 | 0 | 5,800,000 | 29.31 | 1.72 | 68.96 |
| | 1 | 190,000,000 | 5.26 | 84.21 | 10.52 |
| 97 | 0 | ............ | ....... | ....... | ....... |
| | 1 | 22,400,000 | 4.01 | 90.62 | 5.35 |
| | 2 | 186,000,000 | 5.37 | 89.24 | 5.37 |
| 99 | 0 | ............ | ....... | ....... | ....... |
| | 1 | 11,300,000 | 1.76 | 83.18 | 15.04 |
| 101 | 0 | 880,000 | 11.36 | 47.72 | 40.99 |
| 103 | 0 | ............ | ....... | ....... | ....... |
| | 1 | 86,000,000 | 9.30 | 52.32 | 38.38 |
| | 2 | 208,000,000 | 3.36 | 87.01 | 9.61 |
| 105 | 0 | ............ | ....... | ....... | ....... |
| | 1 | 32,000,000 | 9.37 | 46.87 | 43.75 |
| | 2 | 270,000,000 | 7.40 | 92.59 | ....... |
| 107 | 0 | 1,100,000 | 18.18 | 63.63 | 18.18 |
| | 1 | 27,200,000 | 2.20 | 85.29 | 12.50 |
| | 2 | 64,000,000 | 1.56 | 93.75 | 4.68 |
| 109 | 0 | 1,450,000 | 14.48 | 4.13 | 81.37 |
| | 1 | 231,000,000 | 3.03 | 10.38 | 86.58 |
| | 2 | 56,000,000 | 3.57 | 83.92 | 12.50 |
| 111 | 0 | 7,000,000 | 42.85 | 14.28 | 42.85 |
| | 1 | 26,200,000 | 8.01 | 44.27 | 47.70 |
| | 2 | 89,000,000 | 2.24 | 77.52 | 20.23 |
| 113 | 0 | 1,750,000 | 8.57 | 34.28 | 57.14 |
| | 1 | 8,800,000 | 11.36 | 71.59 | 17.04 |
| | 2 | 92,000,000 | 1.08 | 77.17 | 21.73 |
| 115 | 0 | 2,640,000 | 1.51 | 98.48 | ....... |
| | 1 | 10,500,000 | 1.90 | 79.04 | 19.04 |
| | 2 | 76,000,000 | 3.94 | 84.21 | 11.84 |
| 117 | 0 | 400,000 | 2.50 | 85.0 | 12.5 |
| | 1 | 32,000,000 | 9.37 | 53.12 | 37.50 |
| | 2 | 214,000,000 | 1.40 | 26.63 | 71.96 |
| 119 | 0 | 1,140,000 | 1.75 | 92.98 | 5.26 |
| | 1 | 6,000,000 | 16.66 | 83.33 | ....... |
| | 2 | 65,000,000 | 1.53 | 86.15 | 12.30 |
| 121 | 0 | 1,410,000 | 21.98 | 34.04 | 43.97 |
| | 1 | 11,200,000 | 8.03 | 20.53 | 71.42 |

### RAW MILK—DAIRY G.

| Sample No. | Age of milk in days. | Total bacteria per c. c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|
| 147 | 0 | ............ | ....... | ....... | ....... |
| | 1 | 2,920,000 | 4.10 | ....... | 95.89 |
| | 2 | 53,000,000 | 5.66 | 37.73 | 56.60 |
| 149 | 0 | 71100 | 36.61 | 12.67 | 50.70 |
| | 1 | 118,000 | 41.53 | 4.23 | 54.23 |
| | 2 | 4,600,000 | 56.52 | ....... | 43.47 |
| | 3 | 27,000,000 | 25.92 | 18.51 | 55.55 |
| 151 | 0 | 24,400 | 8.60 | 18.03 | 73.36 |
| | 1 | 2,100,000 | 4.76 | 66.66 | 28.57 |
| | 2 | 9,200,000 | 7.60 | 22.82 | 69.56 |
| | 3 | 48,000,000 | 6.25 | 52.08 | 41.66 |
| 153 | 0 | 261,000 | .38 | 97.70 | 1.91 |
| | 1 | 3,500,000 | 2.85 | 80.00 | 17.14 |
| | 2 | 30,000,000 | 3.33 | 60.00 | 36.66 |
| | 3 | 205,000,000 | 2.92 | 80.48 | 16.58 |
| 155 | 0 | 490,000 | 8.16 | 81.63 | 10.20 |
| | 1 | 8,000,000 | 22.50 | 31.25 | 46.25 |
| | 2 | 45,000,000 | 20.00 | 53.33 | 26.66 |
| 157 | 0 | 181,000 | 1.65 | 94.47 | 3.86 |
| | 1 | 10,200,000 | 1.96 | 93.13 | 4.90 |
| 159 | 0 | ............ | ....... | ....... | ....... |
| | 1 | 31,300,000 | 1.59 | 85.62 | 12.77 |
| | 2 | 158,000,000 | 1.89 | 85.44 | 12.65 |
| 161 | 0 | ............ | ....... | ....... | ....... |
| | 1 | 30,900,000 | 3.23 | 85.11 | 11.65 |
| | 2 | 295,000,000 | 1.69 | 30.50 | 67.79 |
| 163 | 0 | ............ | ....... | ....... | ....... |
| | 1 | 145,000,000 | 3.44 | 68.96 | 27.58 |
| 167 | 0 | ............ | ....... | ....... | ....... |
| | 1 | 58,630,000 | .73 | 69.93 | 29.33 |
| | 2 | 265,000,000 | 3.77 | 79.24 | 16.98 |
| | 3 | 660,000,000 | ....... | 92.42 | 7.57 |
| 169 | 0 | ............ | ....... | ....... | ....... |
| | 1 | ............ | ....... | ....... | ....... |
| | 2 | 313,000,000 | 1.59 | 86.26 | 12.14 |
| | 3 | 810,000,000 | 1.23 | 95.06 | 3.7 |
| 170 | 0 | 39,000 | 76.92 | 23.07 | ....... |
| | 1 | 3,900,000 | 23.07 | 30.76 | 46.15 |
| | 2 | 27,200,000 | 9.55 | 37.13 | 53.30 |
| | 3 | 201,000,000 | 1.99 | 83.08 | 14.92 |
| 171 | 0 | ............ | ....... | ....... | ....... |
| | 1 | 4,390,000 | 6.83 | 15.94 | 77.21 |
| | 2 | 37,700,000 | 4.50 | 40.05 | 55.43 |
| 173 | 0 | 120,000 | 50.00 | 25.00 | 25.00 |
| | 1 | 1,800,000 | 13.88 | 32.77 | 53.33 |
| | 2 | 45,500,000 | 3.73 | 62.19 | 34.06 |
| 175 | 0 | 130,000 | 23.07 | 38.46 | 38.46 |
| | 1 | 2,000,000 | 15.00 | 41.00 | 44.00 |
| 177 | 0 | 1,110,000 | 4.50 | 20.72 | 74.77 |
| | 1 | ............ | ....... | ....... | ....... |
| | 2 | 165,000,000 | 1.21 | 20.60 | 78.18 |
| | 3 | 330,000,000 | 24.24 | 60.60 | 15.15 |
| 179 | 0 | ............ | ....... | ....... | ....... |
| | 1 | ............ | ....... | ....... | ....... |
| | 2 | 150,000,000 | 13.33 | 40.00 | 46.66 |
| | 3 | 360,000,000 | 5.27 | 69.72 | 25.00 |
| 181 | 0 | 310,000 | 6.45 | 70.96 | 22.58 |
| | 1 | 25,200,000 | 4.76 | 79.36 | 15.87 |
| | 2 | 185,000,000 | 2.70 | 36.21 | 61.08 |
| | 3 | 320,000,000 | 1.56 | 85.94 | 12.50 |
| 183 | 0 | ............ | ....... | ....... | ....... |
| | 1 | 35,600,000 | 4.21 | 71.06 | 24.71 |
| | 2 | 336,000,000 | .59 | 91.99 | 7.43 |
| 185 | 0 | 128,000 | 3.12 | 87.50 | 9.37 |
| | 1 | 18,000,000 | 3.88 | 69.44 | 26.66 |

TABLE IX.—*Raw and pasteurized milk at Boston, Mass.—Total bacterial counts and group percentages—Milk held at 21° C. (70° F.).*

PASTEURIZED MILK—DAIRY B.

| Sample No. | Age of milk in days. | Total bacteria per c.c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. | Sample No. | Age of milk in days. | Total bacteria per c.c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 46 | 0 | 24,900 | 16.06 | 61.84 | 22.08 | 58 | 0 | 136.000 | 13.97 | 81.61 | 4.41 |
| | 1 | 44,000,000 | 10.9 | 71.13 | 17.95 | | 1 | 540,000,000 | .37 | 99.62 | ....... |
| 48 | 0 | 16,000 | 28.75 | 8.75 | 62.5 | 60 | 0 | 757,000 | 1.585 | 92.47 | 5.94 |
| | 1 | 240,000,000 | 2.91 | 83.33 | 13.75 | | 1 | 395,000,000 | .253 | 70.12 | 29.62 |
| 50 | 0 | 45.000 | 6.66 | 71.11 | 22.22 | 62 | 0 | 155,000 | 12.25 | 61.93 | 25.8 |
| | 1 | 228,000,000 | 3.50 | 92.54 | 3.94 | | 1 | 230,000,000 | 5.21 | 40.43 | 54.34 |
| 52 | 0 | 201.000 | 11.44 | 58.70 | 29.85 | 64 | 0 | 190,000 | 2.631 | 83.68 | 13.68 |
| 54 | 0 | 119.000 | 7.56 | 50.42 | 42.01 | | 1 | 400,000,000 | 1.00 | 75.00 | 24.00 |
| | 1 | 430,000,000 | 6.97 | 65.11 | 27.9 | | | | | | |
| 56 | 0 | 59.000 | 6.77 | 79.66 | 13.55 | | | | | | |
| | 1 | 424,000,000 | 2.12 | 93.39 | 4.48 | | | | | | |

PASTEURIZED MILK—DAIRY A.

| Sample No. | Age of milk in days. | Total bacteria per c.c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. | Sample No. | Age of milk in days. | Total bacteria per c.c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 66 | 0 | ............ | ......... | ......... | ....... | 76 | 0 | 212,000 | 10.84 | 83.01 | 6.13 |
| | 1 | 78,000,000 | 14.10 | 43.58 | 42.30 | | 1 | 299,000,000 | 1.67 | 83.61 | 14.71 |
| 68 | 0 | 48,000 | 16.66 | 83.33 | ....... | 78 | 0 | 65,900 | 2.12 | 5.31 | 92.56 |
| | 1 | 253,000,000 | 7.90 | 80.63 | 11.46 | | 1 | 35,000,000 | 5.71 | 40.00 | 54.28 |
| 70 | 0 | ............ | ......... | ......... | ....... | 80 | 0 | 52,000 | 1.92 | 69.23 | 28.84 |
| | 1 | 151,000,000 | 5.29 | 72.84 | 21.75 | | 1 | 11,200,000 | 2.67 | 72.32 | 25.00 |
| 72 | 0 | 50,200 | 3.98 | 57.76 | 38.24 | 82 | 0 | 38,100 | 26.00 | 34.12 | 65.61 |
| | 1 | 28,000,000 | 17.85 | 67.85 | 14.28 | | 1 | 40,000,000 | 25.00 | 50.00 | 25.00 |
| 74 | 0 | 31,600 | 7.59 | 63.29 | 29.11 | 88 | 0 | 83,100 | .12 | 99.87 | ....... |
| | 1 | 41,000,000 | 31.70 | 26.82 | 41.46 | | | | | | |

PASTEURIZED MILK—DAIRY C.

| Sample No. | Age of milk in days. | Total bacteria per c.c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. | Sample No. | Age of milk in days. | Total bacteria per c.c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 94 | 0 | 3,300,000 | 24.24 | 75.75 | ....... | 102 | 0 | 870.000 | 8.04 | 80.45 | 11.49 |
| | 1 | 204,000,000 | 4.41 | 49 01 | 46.56 | 122 | 0 | 4,200,000 | 2.38 | 61.90 | 35.71 |
| 96 | 0 | 8,250,000 | 3.03 | 36.36 | 60.60 | | 1 | 77,000,000 | 9.09 | 67.53 | 23.37 |
| 98 | 0 | 3,640,000 | 1.63 | 96.15 | 2.19 | | | | | | |
| | 1 | 993,000,000 | .30 | 93.65 | 6.04 | | | | | | |

RAW MILK—DAIRY G.

| Sample No. | Age of milk in days. | Total bacteria per c.c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. | Sample No. | Age of milk in days. | Total bacteria per c.c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 142 | 0 | ............ | ......... | ......... | ....... | 152 | 0 | 83,500 | 4.91 | 91.97 | 3.11 |
| | 1 | 544,000,000 | .55 | 98.71 | .73 | | | | | | |
| 150 | 0 | 5,800 | 29.31 | 24.13 | 46.55 | | | | | | |
| | 1 | 105,000,000 | 4.76 | 76.19 | 19.04 | | | | | | |

**Table X**—*Raw and pasteurized milk at Boston, Mass., in summer—Total bacterial counts and group percentages—Milk held at 10° C. (50° F.).*

PASTEURIZED MILK—DAIRY A.

| Sample No. | Age of milk in days. | Total bacteria per c.c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|
| 272 | 0 | 445,600 | 1.23 | 15.26 | 83.48 |
| | 1 | 2,740,000 | 8.02 | 29.92 | 62.04 |
| | 2 | 214,000,000 | 3.73 | 86.91 | 9.34 |
| 273 | 0 | 97,000 | 6.18 | 3.09 | 90.72 |
| | 1 | 56,200.000 | 6.40 | 60.32 | 33.27 |
| | 2 | 315,000 000 | .63 | 99.36 | ........ |
| 274 | 0 | 784,000 | 8.92 | 61.73 | 29.33 |
| | 1 | 44,000,000 | 13.63 | 40.91 | 45.45 |
| 275 | 0 | 27,000 | 22.22 | 7.41 | 70.37 |
| | 1 | 2,700.000 | 40.74 | ........ | 59.25 |
| | 2 | 22,000,000 | 9.09 | 33.63 | 57.27 |
| | 3 | 77,000,000 | 6.49 | 41.55 | 51.94 |
| 276 | 0 | ........ | ........ | ........ | ........ |
| | 1 | 290,000 | 6.89 | ........ | 93.10 |
| | 2 | 5,000,000 | 40.00 | 40.00 | 20.00 |
| 277 | 0 | 95,000 | 22.10 | 17.98 | 60.00 |
| | 1 | 22,300,000 | 12.10 | 8.07 | 79.82 |
| 278 | 0 | 26,000 | 3.83 | 30.76 | 65.38 |
| | 1 | ........ | ........ | ........ | ........ |
| | 2 | 324,000,000 | 2.46 | 76.85 | 20.67 |
| 279 | 0 | 286,000 | 15.73 | 16.78 | 67.48 |
| | 1 | 90,000,000 | 8.88 | 18.88 | 72.22 |
| | 2 | 161,000,000 | 1.24 | 79.50 | 19.25 |
| 280 | 0 | ........ | ........ | ........ | ........ |
| | 1 | 29,400,000 | .68 | 31.29 | 68.02 |

RAW MILK.

| Sample No. | Age of milk in days. | Total bacteria per c.c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|
| 284 | 0 | 2,570,000 | 7.78 | 33.85 | 58.36 |
| | 1 | 95,000,000 | 6.31 | 28.42 | 65.26 |
| 285 | 0 | 13,900,000 | 10.79 | 78.41 | 10.79 |
| | 1 | 85,000,000 | 1.17 | 80.00 | 18.82 |
| 286 | 0 | 5,000,000 | ........ | 20.00 | 80.00 |
| | 1 | 238,000,000 | 2.51 | 76.47 | 21.00 |
| 287 | 0 | 9,700,000 | 3.09 | 72.16 | 24.74 |
| | 0 | 164,000,000 | 6.70 | 48.17 | 45.12 |
| 288 | 0 | 28,200,000 | 10.63 | 67.37 | 21.98 |
| | 1 | 505,000,000 | ........ | 99.80 | .19 |
| 289 | 0 | 43,100,000 | .92 | 95.59 | 3.46 |
| | 1 | 200,000,000 | .50 | 99.50 | ........ |
| 290 | 0 | 8,800,000 | 3.49 | 82.95 | 13.63 |
| | 1 | 106,000,000 | 4.71 | 80.18 | 15.09 |
| 291 | 0 | 11,400,000 | 5.26 | 84.21 | 10.52 |
| | 1 | 124,000,000 | .80 | 92.74 | 6.45 |
| 292 | 0 | 11,200,000 | 18.75 | 63.39 | 17.85 |
| | 1 | 177,000,000 | 5.64 | 56.49 | 37.85 |
| | 2 | 158,000,000 | 2.53 | 97.46 | ........ |
| 293 | 0 | 4,500,000 | 22.22 | 31.11 | 46.66 |
| | 1 | 79,000,000 | 10.12 | 30.37 | 59.49 |
| | 2 | 459,000,000 | 6.97 | 18.51 | 74.50 |
| 294 | 0 | 1,900,000 | 10.52 | 40.00 | 49.47 |
| | 1 | 18,500,000 | 4.32 | 41.62 | 54.05 |
| 295 | 0 | 3,050,000 | 4.59 | 66.53 | 28.85 |
| | 1 | ........ | ........ | ........ | ........ |
| 297 | 0 | ........ | ........ | ........ | ........ |
| | 1 | 235,000,000 | 29.78 | 2.12 | 68.08 |
| 298 | 0 | 3,400,000 | 13.52 | 33.52 | 52.94 |
| | 1 | 80,000,000 | (a) | 75.00 | 25.00 |
| 299 | 0 | 5,700,000 | 1.75 | 10.52 | 87.71 |
| | 1 | 200,000,000 | ........ | 60.00 | 40.00 |

[a] 0 in 10,000,000 dilutions.

TABLE XI.—*Raw and pasteurized milk in New York City, examined February and March, 1909—Daily acidity, total bacterial counts, and group percentages—Milk held at 10° C. (50° F.).*

PASTEURIZED MILK.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 201 | 0 | 0.21 | [a] 11,200 | 600 | L. A. [b] 6,400 | [b] 4,200 | From dairy H, Nos. 201–221, inclusive, pasteurized "holder" process, 60°–65.6° C. (140°–150° F.). |
| | 1 | .22 | [a]42,000 | 1,000 | 1,000 | 40,000 | |
| | 2 | .21 | [a] 900,000 | 50,000 | 20,000 | 830,000 | |
| | 3 | .21 | [a] 7,900,000 | 7,600,000 | 0 | [c] 6,300,000 | |
| | 4 | | | | | | |
| | 5 | .22 | [a] 47,100,000 | 2,000,000 | 31,500,000<br>L. A. 2,000,000 | 11,600,000 | |
| | 6 | | | | | | |
| | 7 | .63 | [a] 457,000,000 | 15,000,000 | 400,000,000 | 42,000,000 | Sour and gas. |
| | 8 | .74 | [a] 575,000,000 | 2,000,000 | 540,000,000 | 32,000,000 | |
| | 9 | .81 | | | | | |
| 203 | 0 | .20 | [a] 10,000 | 0 | 1,000 | 9,000 | |
| | 1 | .20 | [a] 50,000 | | | 50,000 | Dilution too high. |
| | 2 | .18 | [a] 4,000,000 | 900,000 | [d] 3,100,000 | | |
| | 3 | | | | | | |
| | 4 | .21 | [a] 21,600,000 | 1,100,000 | 2,000,000<br>L. A. 8,600,000 | 9,900,000 | |
| | 5 | | | | | | |
| | 6 | .41 | [a] 403,000,000 | 3,000,000 | 250,000,000<br>L.A. 100,000,000 | 50,000,000 | Slight cheesy flavor; would not be used. |
| | 7 | .52 | [a] 331,000,000 | 2,000,000 | 176,000,000<br>L. A. 87,000,000 | 66,000,000 | Gas. |
| | 8 | .66 | | | | | |
| 205 | 0 | .19 | [a] 29,800 | 600 | 3,000 | 26,200 | |
| | 1 | .18 | [a] 59,000 | 1,000 | 5,000 | 53,000 | |
| | 2 | | | | | | |
| | 3 | .20 | [a] 1,300,000 | 100,000 | 200,000 | 1,000,000 | |
| | 4 | | | | | | |
| | 5 | .18 | [a] 26,800,000 | 900,000 | 6,000,000 | 1,990,000 | |
| | 6 | .23 | [a] 69,000,000 | 6,000,000 | 19,000,000<br>L. A. 9,000,000 | 35,000,000 | Slight cheesy flavor. |
| | 7 | .31 | [a] 206,000,000 | 4,000,000 | 153,000,000 | 49,000,000 | |
| | 8 | .56 | | | | | |
| 207 | 0 | .18 | 8,300 | 200 | 1,000 | 8,600 | |
| | 1 | | | | | | |
| | 2 | .18 | 1,330,000 | 14,000 | 25,000 | 270,000 | |
| | 3 | | | | | | |
| | 4 | .19 | 18,000,000 | 1,300,000 | 3,000,000 | 9,800,000 | |
| | 5 | .21 | 87,000,000 | 7,000,000 | 12,000,000<br>L. A. 8,000,000 | 26,000,000 | |
| | 6 | .24 | 360,000,000 | 2,000,000 | 133,000,000 | 54,000,000 | |
| | 7 | .39 | | | | | |
| [e] 209 | 0 | | | | | | |
| | 1 | .19 | 8,000 | 900 | 1,200 | 7,100 | |
| | 2 | | | | | | |
| | 3 | .19 | 3,000,000 | 170,000 | 20,000<br>L. A. 100,000 | 3,000,000 | |
| | 4 | .22 | 24,000,000 | 1,000,000 | 900,000 | 17,700,000 | |
| | 5 | .20 | 88,000,000 | 4,000,000 | 22,000,000 | 38,000,000 | |
| | 6 | .39 | 360,000,000 | 8,000,000 | 156,000,000<br>L. A. 30,000,000 | 81,000,000 | |
| | 7 | .63 | | | | | Sour. |
| | 8 | .83 | | | | | |
| 211 | 0 | .21 | 7,900 | 1,000 | 11,000 | 9,000 | |
| | 1 | | | | | | |
| | 2 | .27 | 2,080,000 | 270,000 | 20,000<br>L. A. 70,000 | 1,700,000 | |
| | 3 | .27 | 14,500,000 | 1,000,000 | 400,000 | 14,500,000 | |
| | 4 | .24 | 63,000,000 | 3,000,000 | 26,000,000 | 31,000,000 | |
| | 5 | .33 | 380,000,000 | 3,000,000 | 170,000,000<br>L. A. 30,000,000 | 65,000,000 | |
| | 6 | .60 | | | | | Sour and cheesy. |

[a] Gelatin.
[b] Or acid.
[c] Probably some acid colonies.
[d] Or alkali.
[e] Sample held in hotel refrigerator.

TABLE XI.—*Raw and pasteurized milk in New York City, examined February and March, 1909—Daily acidity, total bacterial counts, and group percentages—Milk held at 10° C. (50° F.)*—Continued.

PASTEURIZED MILK—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 213 | 0 | 0.19 | 55,300 | 53,000 | 3,000 | 70,000 | |
| | 1 | .19 | 14,000 | 0 | 14,000 | 3,000 | 0 in 1,000 dilutions. |
| | 2 | .18 | 120,000 | 10,000 | [a]200,000 | | |
| | 3 | .19 | [b]14,000,000 | 4,000,000 | 3,000,000 | 7,000,000 | |
| | 4 | .24 | 220,000,000 | 1,000,000 | 170,000,000<br>L. A. 26,000,000 | 16,000,000 | |
| | 5 | .37 | | | | | |
| | 6 | | | | | | |
| | 7 | | | | | | |
| | 8 | 1.05 | | | | | Coagulated. |
| 215 | 0 | .18 | 12,800 | 1,000 | 11,000 | 6,000 | |
| | 1 | .20 | 24,000 | 22,000 | 3,000 | 15,000 | |
| | 2 | .18 | 4,000,000 | 800,000 | 400,000 | 1,500,000 | |
| | 3 | .20 | 39,300,000 | 4,000,000 | 14,000,000<br>L. A. 6,000,000 | 9,000,000 | |
| | 4 | .34 | | | | | |
| | 5 | | | | | | |
| | 6 | | | | | | |
| | 7 | 1.05 | | | | | Do. |
| 217 | 0 | .19 | 6,900 | 400 | L. A. 1,500 | 4,000 | |
| | 1 | .19 | 6,000 | 4,000 | 2,000 | 8,000 | |
| | 2 | .19 | 12,300,000 | 1,000,000 | 400,000<br>L. A. 500,000 | 12,000,000 | |
| | 3 | .21 | 205,000,000 | 1,000,000 | 115,000,000<br>L. A. 30,000,000 | 17,000,000 | |
| | 4 | | | | | | |
| | 5 | | | | | | |
| | 6 | .95 | | | | | Do. |
| 219 | 0 | .19 | 13,700 | 300 | 900 | 12,900 | |
| | 1 | .19 | 54,000 | 14,000 | L. A. 3,000 | 70,000 | |
| | 2 | .20 | 1,780,000 | 100,000 | 600,000 | 1,000,000 | |
| | 3 | | | | | | |
| | 4 | | | | | | |
| | 5 | .71 | | | | | Sour. |
| 221 | 0 | .19 | 18,850 | 300 | 10,600 | 15,700 | |
| | 1 | .19 | 845,000 | 110,000 | 10,000 | 1,050,000 | |
| | 2 | | | | | | |
| | 3 | | | | | | |
| | 4 | .50 | | | | | Slightly sour. |
| 225 | 0 | .18 | 465,000 | 1,000 | 340,000 | 190,000 | No. 225-235, inclusive, from dairy K, pasteurized "flash" process, 71.1° C. (160° F.). |
| | 1 | .18 | 490,000 | 0 | 370,000 | 70,000 | |
| | 2 | .18 | 1,160,000 | 300,000 | 700,000<br>L. A. 100,000 | 500,000 | |
| | 3 | .24 | 22,600,000 | 4,000,000 | 4,000,000 | 16,000,000 | Old taste, probably; would not be used. |
| | 4 | .27 | 129,000,000 | 4,000,000 | 69,000,000<br>L. A. 4,000,000 | 37,000,000 | |
| | 5 | | | | | | |
| | 6 | .72 | 1,140,000,000 | 0 | 830,000,000 | 50,000,000 | Sour. |
| | 7 | .81 | | | | | Do. |
| | 8 | .99 | | | | | Smooth curd. |
| 227 | 0 | .20 | 7,400 | 1,300 | 2,100 | 18,100 | |
| | 1 | .21 | 31,000 | 10,000 | 18,000 | 40,000 | |
| | 2 | .20 | 4,910,000 | 700,000 | 500,000 | 1,100,000 | |
| | 3 | .27 | | | | | Old taste; would not be used. |
| | 4 | | | | | | |
| 229 | 0 | .20 | 15,000 | 800 | 1,100 | 15,000 | |
| | 1 | .20 | 160,000 | 6,000 | 105,000 | 9,000 | |
| | 2 | .20 | 14,000,000 | 3,000,000 | 2,000,000 | 10,000,000 | |
| | 3 | | | | | | |
| | 4 | .59 | | | | | Sour. |

[a] Acid or alkali.

[b] Gelatin.

**Table XI.**—*Raw and pasteurized milk in New York City, examined February and March, 1909—Daily acidity, total bacterial counts, and group percentages—Milk held at 10° C. (50° F.)*—Continued.

PASTEURIZED MILK—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 231 | 0 | 0.20 | 18,000 | 500 | 6,600<br>L. A. 200 | 18,000 | |
| | 1 | .19 | 140,000 | | | | Gelatin; liquefied. |
| | 2 | | | | | | |
| | 3 | .24 | 177,000,000 | 1,000,000 | 81,000,000<br>L. A. 4,000,000 | 34,000,000 | Old taste; would not be used. |
| | 4 | .37 | | | | | Sour. |
| | 5 | .76 | | | | | |
| | 6 | .87 | | | | | Curdled. |
| 233 | 0 | .20 | 15,600 | 800 | 11,200<br>L. A. 500 | 24,200 | |
| | 1 | .19 | 50,000 | | | | |
| | 2 | | | | | | |
| | 3 | .26 | 255,000,000 | 1,100,000 | 116,000,000<br>4,000,000 | 30,000,000 | Old taste. |
| | 4 | .53 | | | | | Sour. |
| | 5 | .86 | | | | | Curdled (smooth). |
| 235 | 0 | .22 | 14,000 | 1,400 | 2,800 | 12,800 | |
| | 1 | | | | | | |
| | 2 | .21 | 3,490,000 | 400,000 | 100,000 | 1,900,000 | |
| | 3 | .20 | 54,000,000 | 600,000 | 300,000 | 2,400,000 | |
| | 4 | .37 | | | | | |
| | 5 | .81 | | | | | Curdled. |
| 237 | 0 | .21 | 23,700 | 300 | 10,000 | 6,200 | Nos. 237–245, inclusive, from dairy M, pasteurized "flash" process, 70° C. (158° F.). |
| | 1 | .19 | 1,500,000 | 90,000 | 650,000 | 870,000 | |
| | 2 | .19 | 13,150,000 | 200,000 | 7,400,000 | 2,400,000 | |
| | 3 | .26 | | | | | Old taste (might be used). |
| | 4 | .35 | | | | | Slightly sour. |
| | 5 | | | | | | |
| | 6 | .83 | | | | | |
| 239 | 0 | .18 | 36,400 | 21,000 | 3,000 | 1,400 | |
| | 1 | .18 | 15,140,000 | 4,000,000 | 100,000 | 8,300,000 | |
| | 2 | .20 | 4,900,000 | 240,000 | 5,300,000 | 300,000 | |
| | 3 | .20 | 107,000,000 | 8,000,000 | 30,000,000 | 14,000,000 | |
| | 4 | | | | | | |
| | 5 | .69 | | | | | Sour. |
| | 6 | .90 | | | | | |
| | 7 | 1.0 | | | | | |
| | 8 | 1.2 | | | | | Partly curdled. |
| 241 | 0 | .19 | 17,400 | 900 | 2,900 | 9,600 | |
| | 1 | .19 | 2,500,000 | 130,000 | 60,000 | 760,000 | |
| | 2 | | | | | | |
| | 3 | .24 | 167,000,000 | 19,000,000 | 64,000,000 | 26,000,000 | Old, cheesy; would not be used. |
| | 4 | .62 | | | | | Slightly sour. |
| | 5 | .79 | | | | | Sour. |
| 243 | 0 | .19 | 7,300 | 1,200 | 0 | 5.500 | 0 in 100 dilutions. |
| | 1 | .20 | 470.000 | 10,000 | L. A. 10,000 | 140,000 | |
| | 2 | .21 | 5,600,000 | 500.000 | 300,000 | 1,600,000 | |
| | 3 | .20 | 81,000,000 | 2,000,000 | 22,000,000<br>L. A. 2,000,000 | 36.000,000 | Old taste. |
| | 4 | .37 | | | | | Slightly sour. |
| 245 | 0 | .18 | 12,400 | 3,800 | 200 | 4.000 | |
| | 1 | .18 | | | | | |
| | 2 | .20 | 2,700.000 | 0 | 300.000 | 2,700,000 | |
| | 3 | .20 | 28,600.000 | 8,000,000 | 14,000,000 | 17.000,000 | |
| | 4 | .25 | 62,000,000 | 11,000,000 | 7.000,000 | 20,000,000 | Slightly sour; would not be used. |
| | 5 | | | | | | |
| | 6 | .52 | | | | | |

TABLE XI.—*Raw and pasteurized milk in New York City, examined February and March, 1909—Daily acidity, total bacterial counts, and group percentages—Milk held at 10° C. (50° F.)*—Continued.

### CERTIFIED RAW MILK.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 251 | 0 | 0.18 | 100 | 0 | 0 | 300 | From dairy H, No. 251. |
| | 1 | .18 | 200 | | | | |
| | 2 | .16 | 3,000 | 1,000 | 0 | 1,000 | |
| | 3 | .18 | 13,800,000 | 400,000 | 0 | 16,700,000 | |
| | 4 | .18 | 13,000,000 | 3,000,000 | 0 | 12,000,000 | |
| | 5 | .18 | 35,000,000 | 2,400,000 | 0 | 22,300,000 | |
| | 6 | | | | | | |
| | 7 | .23 | 77,000,000 | 9,000,000 | 3,000,000 | 41,000,000 | Putrid taste and odor; would not use. |
| | 8 | .32 | | | | | Strong putrid odor. |
| | 9 | .54 | | | | | Strong putrid odor; sour. |
| | 10 | .73 | | | | | |
| **RAW MILK.** | | | | | | | |
| 253 | 0 | 0.19 | 288,000 | 7,000 | 125,000 | 16,000 | Raw milk, dairy P, Nos. 253 and 261. |
| | 1 | .20 | 3,000,000 | 60,000 | 1,310,000<br>L. A. 30,000 | 40,000 | |
| | 2 | .19 | 6,000,000 | 4,000,000 | 0 | 2,000,000 | |
| | 3 | | | | | | |
| | 4 | .19 | 42,000,000 | 3,000,000 | 9,000,000 | 3,000,000 | Old taste. |
| | 5 | .31 | | | | | Slightly sour; would not use. |
| | 6 | .45 | | | | | Sour, thickened. |
| 261 | 0 | .18 | 44,500 | 1,100 | 34,000 | 9,000 | |
| | 1 | .18 | 580,000 | 0 | 470,000<br>L. A. 40,000 | 120,000 | |
| | 2 | .18 | 10,200,000 | 1,200,000 | 1,200,000<br>L. A. 700,000 | 1,200,000 | |
| | 3 | .18 | 106,000,000 | 7,000,000 | 35,000,000<br>L. A. 2,000,000 | 17,000,000 | |
| | 4 | .21 | 294.000,000 | 15,000,000 | 63,000,000 | 44,000,000 | Sweet. |
| | 5 | | | | | | |
| | 6 | .47 | | | | | Sour. |
| 255 | 0 | .18 | 101,000 | 12,000 | 11,000 | 9,000 | From dairy N, Nos. 255–259, inclusive. |
| | 1 | .18 | 560,000 | 30,000 | 30,000 | 70,000 | |
| | 2 | .20 | 6,000,000 | 1,300,000 | 400,000 | 3,400,000 | |
| | 3 | .19 | 210,000,000 | 5,000,000 | 90,000,000 | 51,000,000 | Old taste. |
| | 4 | | | | | | |
| | 5 | .30 | 160,000,000 | 22,000,000 | 54,000,000<br>L. A. 2,000,000 | 47,000,000 | Artificial sweet taste. |
| | 6 | .42 | | | | | Slightly sour, old taste; would not be used. |
| | 7 | .57 | | | | | Sour. |
| | 8 | .72 | | | | | Partly curdled. |
| 257 | 0 | .18 | 261,000 | 30,000 | 80,000 | 60,000 | |
| | 1 | .19 | 140,000 | 20,000 | 150,000 | 30,000 | |
| | 2 | .18 | 5,400,000 | 2,700,000 | 100,000 | 2,700,000 | |
| | 3 | | | | | | |
| | 4 | .18 | 103,000,000 | 15,000,000 | 7,000,000 | 38,000,000 | Slightly old taste. |
| | 5 | .18 | 121,000,000 | 28,000,000 | 11,000,000 | 47,000,000 | Nutty flavor; might be used. |
| | 6 | .18 | | | | | Slightly putrid smell. |
| | 7 | .31 | | | | | Slightly sour. |
| | 8 | .53 | | | | | Sour. |
| | 9 | .64 | | | | | Curdled, whey. |
| 259 | 0 | .18 | 548,000 | 50,000 | 500,000<br>L. A. 10,000 | 20,000 | |
| | 1 | .18 | 4,500,000 | 1,300,000 | 300,000<br>L. A. 400,000 | 2,000,000 | |
| | 2 | | | | | | |
| | 3 | .18 | 58,500,000 | 2,000,000 | 10,600,000<br>L. A. 600,000 | 8,700,000 | |

**Table XI.**—*Raw and pasteurized milk in New York City, examined February and March, 1909—Daily acidity, total bacterial counts, and group percentages—Milk held at 10° C. (50° F.)*—Continued.

RAW MILK—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 259 | 4 | 0.18 | 149,000,000 | 18,000,000 | 55,000,000 | 41,000,000 | Old taste; might be used. |
|  | 5 | .26 | ... | ... | ... | ... | Slightly sour; slightly putrid taste. |
|  | 6 | .38 | ... | ... | ... | ... | Sour. |
|  | 7 | .54 | ... | ... | ... | ... |  |
|  | 8 | .64 | ... | ... | ... | ... |  |
| 263 | 0 | .18 | 21,300,000 | 2,800,000 | 500,000 | 17,800,000 | Nos. 263-269, inclusive, from stores. |
|  | 1 | .18 | 90,000,000 | 8,000,000 | 29,000,000<br>L. A. 7,000,000 | 58,000,000 |  |
|  | 2 | .18 | 179,000,000 | 17,000,000 | 45,000,000<br>L. A. 8,000,000 | 89,000,000 |  |
|  | 3 | .35 | 318,000,000 | 9,000,000 | 134,000,000<br>L. A. 9,000,000 | 77,000,000 | Sour; would not be used. |
|  | 4 | ... | ... | ... | ... | ... |  |
|  | 5 | .57 | ... | ... | ... | ... | Sour. |
| 265 | 0 | .18 | 348,000 | 13,000 | 278,000 | 24,000 |  |
|  | 1 | .18 | 1,040,000 | 170,000 | 260,000 | 300,000 |  |
|  | 2 | .18 | 17,700,000 | 3,600,000 | 1,000,000 | 2,900,000 |  |
|  | 3 | .18 | 101,000,000 | 23,000,000 | 3,000,000<br>L. A. 1,000,000 | 13,000,000 |  |
|  | 4 | .20 | 102,000,000 | 25,000,000 | 10,000,000<br>L. A. 10,000,000 | 34,000,000 | Old taste; would not be used. |
|  | 5 | .26 | 312,000,000 | 30,000 | ... | ... | Old taste. |
|  | 6 | ... | ... | ... | ... | ... |  |
|  | 7 | .54 | ... | ... | ... | ... | Sour. |
| 267 | 0 | .17 | 61,000 | 2,000 | 17,000 | 21,000 |  |
|  | 1 | .18 | 500,000 | 80,000 | 100,000<br>L. A. 60,000 | 100,000 |  |
|  | 2 | .18 | 9,500,000 | 2,300,000 | 300,000 | 4,500,000 |  |
|  | 3 | .18 | 80,000,000 | 15,000,000 | 10,000,000 | 14,000,000 | Might be used; slightly off taste; part of plate liquefied. |
|  | 4 | ... | ... | ... | ... | ... |  |
|  | 5 | .32 | ... | ... | ... | ... | Slightly sour; bitter taste. |
| 269 | 0 | .18 | 131,000 | 22,000 | 31,000 | 14,000 |  |
|  | 1 | .18 | 1,500,000 | 100,000 | 500,000 | 800,000 |  |
|  | 2 | .18 | 130,000,000 | 12,000,000 | 33,000,000 | 34,000,000 |  |
|  | 3 | ... | ... | ... | ... | ... |  |
|  | 4 | .31 | ... | ... | ... | ... | Slightly sour; would not be used. |

**Table XII.**—*Raw and pasteurized milk in New York City—Milk held at room temperature, 20° C. (68° F.).*

PASTEURIZED MILK.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 202 | 0 | 0.22 | [a] 8,600 | 300 | [b] 4,100 | 4,200 | From dairy H, Nos. 202-220, inclusive. |
|  | 1 | .22 | [a] 2,850,000 | 270,000 | [b] 20,000 | 2,560,000 |  |
|  | 2 | .38 | [a] 417,000,000 | 7,000,000 | 210,000,000 | [c] 200,000,000 | Slightly sour. |
|  | 3 | .99 | ... | ... | ... | ... | Curdled; smooth. |

[a] Gelatin. [b] Or L. A. [c] Or acid.

TABLE XII.—*Raw and pasteurized milk in New York City—Milk held at room temperature, 20° C. (68° F.)*—Continued.

PASTEURIZED MILK—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 204 | 0 | 0.21 | [a]20,600 | 600 | [b]2,000 | 18,000 | |
| | 1 | .21 | [a]4,300,000 | 400,000 | [b]600,000 | 3,300,000 | |
| | 2 | .68 | | | | | Sour. |
| | 3 | .97 | | | | | Curdled. |
| 206 | 0 | .19 | [a]32,200 | 1,200 | 5,000 | 26,000 | |
| | 1 | .18 | [a]15,500,000 | 1,300,000 | 8,700,000 | 5,500,000 | |
| | 2 | | | | | | |
| | 3 | .98 | [a]521,000,000 | 7,000,000 | 400,000,000 | 114,000,000 | Curdled; gas; sweet-smelling curd. |
| 208 | 0 | .18 | 5,700 | 200 | [b]1,000 | 7,500 | |
| | 1 | | | | | | |
| | 2 | .53 | 320,000,000 | 6,000,000 | 104,000,000<br>L. A. 23,000,000 | 68,000,000 | Sour; would not be used. |
| | 3 | | | | | | |
| | 4 | .99 | 780,000,000 | 1,000,000 | 360,000,000 | 24,000,000 | Curdled; smooth. |
| 212 | 0 | .21 | 6,400 | 500 | 13,500 | 15,000 | |
| | 1 | | | | | | Low temperature over Sunday. |
| | 2 | .60 | 430,000,000 | 10,000,000 | 300,000,000 | 90,000,000 | Sour; would not be used. |
| | 3 | .84 | | | | | |
| 214 | 0 | .19 | [a]14,800 | 200 | [b]300 | 14,300 | |
| | 1 | .19 | 1,120,000 | 140,000 | 150,000 | 500,000 | Temperature low at night. |
| | 2 | .30 | 200,000,000 | 4,000,000 | 190,000,000<br>L. A. 30,000,000 | 30,000,000 | |
| | 3 | .85 | | | | | Curdled; smooth. |
| 216 | 0 | .19 | 10,200 | 300 | 3,000 | 4,000 | |
| | 1 | .19 | 1,140,000 | 300,000 | 100,000 | 500,000 | Temperature low at night. |
| | 2 | .26 | 200,000,000 | 3,000,000 | 240,000,000<br>L. A. 39,000,000 | 30,000,000 | |
| | 3 | .92 | | | | | Curdled; smooth. |
| 218 | 0 | 19 | 7,900 | 600 | [b]3,800 | 8,800 | |
| | 1 | .18 | 1,000,000 | 300,000 | 400,000 | 700,000 | |
| | 2 | .56 | | | | | Sour. |
| 220 | 0 | .19 | 11,100 | 400 | 1,600 | 22,300 | |
| | 1 | .19 | 3,450,000 | 1,500,000 | [b]1,200,000 | 13,600,000 | |
| | 2 | .93 | | | | | Sour; smooth curd. |
| [c]224 | 0 | | | | | | From dairy K; pasteurized 71.1° C. (160° F.) "flash" process, Nos. 224-236, inclusive. |
| | 1 | .45 | 588,000,000 | 1,000,000 | 570,000,000 | | Plate acid; slightly sour. |
| | 2 | 1.01 | | | | | Curdled. |
| 226 | 0 | .18 | 370,000 | 3,000 | 540,000 | | Plate acid. |
| | 1 | .19 | 5,000,000 | 400,000 | 2,700,000<br>L. A. 1,100,000 | 2,500,000 | |
| | 2 | .81 | | | | | Sour; curdled in afternoon. |
| 228 | 0 | .20 | 10,200 | 500 | [b]1,900 | 28,000 | |
| | 1 | .20 | 11,400,000 | 100,000 | 4,400,000<br>L. A. 900,000 | 500,000 | |
| | 2 | .80 | | | | | Curdled; gas. |
| 230 | 0 | .20 | 8,300 | 500 | 1,100<br>L. A. 300 | 30,500 | |
| | 1 | [d].19<br>[e].24 | 13,500,000 | 100,000 | 5,800 000 | 1,600,000 | Slightly sour. |
| | 2 | .86 | | | | | Sour; curdled. |

[a] Gelatin. [b] Or L. A. [c] Held in hotel room. [d] 9 a. m. [e] 3 p. m.

**Table XII.**—*Raw and pasteurized milk in New York City—Milk held at room temperature 20° C. (68° F.)*—Continued.

PASTEURIZED MILK—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 236 | 0 | 0.22 | 13,600 | 3,000 | 1,100 | 11,500 | |
| | 1 | ... | ... | ... | ... | ... | Temperature low. |
| | 2 | .31 | ... | ... | ... | ... | Slightly sour; would not be used. |
| | 3 | .90 | ... | ... | ... | ... | Curdled. |
| 238 | 0 | .18 | 18,400 | 2,000 | 9,000 | 4,000 | Dairy M, Nos. 238-246, inclusive; pasteurized 70° C. (158° F.-"flash" process. |
| | 1 | [a].20 | 87,000,000 | 300,000 | 23,600,000 | 11,200,000 | |
| | | [b].27 | ... | ... | ... | ... | Slightly sour; would not be used. |
| | 2 | .79 | ... | ... | ... | ... | Sour. |
| 240 | 0 | .18 | 15,000 | 900 | 400 | 4,100 | |
| | 1 | .18 | 23,400,000 | 400,000 | 600,000 | 8,600,000 | |
| | 2 | .27 | ... | ... | ... | ... | Slightly sour; would not be used. |
| 242 | 0 | .19 | 60,900 | 1,100 | 1,800 | 4,700 | |
| | 1 | .22 | 540,000,000 | 3,000,000 | 17,000,000<br>L. A. 5,000,000 | 48,000,000 | Slightly sour or old taste; would not be used. |
| | 2 | ... | ... | ... | ... | ... | |
| | 3 | 1.12 | ... | ... | ... | ... | Curdled; gas. |
| 244 | 0 | .19 | 37,600 | 5,500 | 400 | 14,300 | |
| | 1 | [a].20 | 17,000,000 | 4,900,000 | 400,000 | 11,500,000 | |
| | | [b].25 | ... | ... | ... | ... | Old taste. |
| | 2 | .79 | ... | ... | ... | ... | Smooth curd; sour. |
| 246 | 0 | .18 | 7,000 | 1,100 | 300 | 2,300 | |
| | 1 | .18 | 27,400,000 | 500,000 | 3,600,000 | 8,600,000 | |
| | 2 | .84 | ... | ... | ... | ... | Curdled; sour. |

CERTIFIED RAW MILK.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 252 | 0 | 0.18 | 500 | 0 | 0 | 200 | From dairy H, No. 252. |
| | 1 | .19 | 22,000 | 0 | 0 | 10,000 | |
| | 2 | .18 | 55,000,000 | 14,000,000 | 3,000,000 | 6,000,000 | |
| | 3 | .69 | 840,000,000 | 14,000,000 | 317,000,000 | 150,000,000 | Partly coagulated. |

RAW MILK.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 254 | 0 | 0.19 | 420,000 | 20,000 | 130,000 | 50,000 | From dairy P, Nos. 254 and 262. |
| | 1 | [a].20 | 60,000,000 | 7,000,000 | 17,000,000<br>L. A. 3,000,000 | 13,000,000 | Slightly off taste. |
| | | [b].27 | ... | ... | ... | ... | Slightly sour. |
| | 2 | .73 | 1,044,000,000 | 50,000,000 | 160,000,000 | 50,000,000 | Not curdled, but sour. |
| | 3 | ... | ... | ... | ... | ... | |
| | 4 | 1.10 | ... | ... | ... | ... | Curdled; smooth curd. |
| 262 | 0 | .18 | 46,800 | 5,200 | 18,900 | 20,000 | |
| | 1 | .23 | 324,000,000 | 0 | 205,000,000<br>L. A. 1,000,000 | 12,000,000 | Would not be used. |
| | 2 | .72 | ... | ... | ... | ... | Curdled; sour; smooth |
| 256 | 0 | .18 | 81,000 | 15,000 | 19,000 | 11,000 | From dairy N, Nos. 256-262. |
| | 1 | .36 | 624,000,000 | 9,000,000 | 33,000,000<br>L. A. 7,000,000 | 60,000,000 | Would not be used. |
| | 2 | .90 | ... | ... | ... | ... | Curdled. |
| 258 | 0 | .18 | 284,000 | 40,000 | 60,000 | 40,000 | |
| | 1 | .18 | 18,000,000 | 3,200,000 | 4,500,000<br>L. A. 500,000 | 6,500,000 | Very slightly sour; might use. |
| | 2 | .72 | ... | ... | ... | ... | Curdled; gas. |

[a] 9 a. m. [b] 3 p. m.

**TABLE XII.**—*Raw and pasteurized milk in New York City—Milk held at room temperature, 20° C. (68° F.)*—Continued.

RAW MILK—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose agar. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 260 | 0 | 0.18 | 376,000 | 22,000 | 190,000 | 28,000 | |
| | 1 | .61 | 1,300,000,000 | 2,000,000 | 94,000,000 | 13,000,000 | Part coagulated temperature 75°-80° F. |
| 264 | 0 | .18 | 22,700,000 | 2,700,000 | 1,200,000 | 13,900,000 | From stores, Nos. 264-270. |
| | 1 | .41 | .... | .... | .... | .... | Sour; would not be used. |
| 266 | 0 | .18 | 280,000 | 7,000 | 205,000 | 58,000 | |
| | 1 | [a] .18<br>[b] .20 | 77,000,000<br>.... | 17,000,000<br>.... | 36,000,000<br>.... | 17,000,000<br>.... | Slightly sour; might be used. |
| | 2 | .62 | .... | .... | .... | .... | |
| 268 | 0 | .17 | 46,000 | 2,000 | 6,000 | 10,000 | |
| | 1 | .18 | 110,000,000 | 6,000,000 | 8,000,000 | 18,000,000 | |
| | 2 | .... | .... | .... | .... | .... | Curdled; smooth curd. |
| 270 | 0 | .18 | 125,000 | 34,000 | 30,000 | 18,000 | |
| | 1 | .19 | 284,000,000 | 15,000,000 | 84,000,000<br>L. A. 3,000,000 | 62,000,000 | |
| | 2 | .69 | .... | .... | .... | .... | Do. |

[a] 9 a. m.

[b] 3 p. m.

**TABLE XIII.**—*Raw and pasteurized milk in New York City—Daily total bacterial counts and group percentages—Milk held at 10° C. (50° F.).*

PASTEURIZED MILK—DAIRY H.

| Sample No. | Age of milk in days. | Total bacteria per c. c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|
| 201... | 0 | 11,200 | 5.35 | 57.14 | 37.5 |
| | 1 | 42,000 | 2.36 | 2.36 | 94.7 |
| | 2 | 882,000 | 5.66 | .22 | 94.1 |
| | 3 | 7,900,000 | 20.2 | .... | 97.7 |
| | 4 | .... | .... | .... | .... |
| | 5 | 47,100,000 | 4.24 | 71.12 | 24.63 |
| | 6 | 457,000,000 | 3.28 | 87.52 | 9.19 |
| | 7 | 575,000,000 | .34 | 93.90 | 5.56 |
| 203... | 0 | 10,000 | .... | 10.00 | 90.00 |
| | 1 | 50,000 | .... | .... | 100.00 |
| | 2 | 4,000,000 | 22.50 | 77.5 | .... |
| | 3 | .... | .... | .... | .... |
| | 4 | 20,600,000 | 5.09 | 49.07 | 45.83 |
| | 5 | .... | .... | .... | .... |
| | 6 | 403,000,000 | .74 | 86.84 | 12.40 |
| | 7 | 331,000,000 | .60 | 79.40 | 19.90 |
| 205... | 0 | 29,800 | 2.01 | 9 86 | 87.87 |
| | 1 | 59,000 | 1.69 | 8.47 | 89.83 |
| | 2 | .... | .... | .... | .... |
| | 3 | 1,300,000 | 7.69 | 15.3 | 76.92 |
| | 4 | 26,800,000 | 3.35 | 22.38 | 74.33 |
| | 5 | 69,000,000 | 8.69 | 40.57 | 50.72 |
| | 6 | 206,000,000 | 1.94 | 74.27 | 23.78 |
| 207... | 0 | 9,800 | 2.04 | 10.20 | 87.75 |
| | 1 | .... | .... | .... | .... |
| | 2 | 309,000 | 4.53 | 8.09 | 87.37 |
| | 3 | .... | .... | .... | .... |
| | 4 | 14,100.000 | 9.21 | 21.27 | 69.50 |
| | 5 | 53,000,000 | 13.20 | 37.73 | 49.05 |
| | 6 | 189,000,000 | 1.05 | 70.37 | 28.57 |
| 209... | 0 | .... | .... | .... | .... |
| | 1 | 9,200 | 9.78 | 13.04 | 77.17 |
| | 2 | .... | .... | .... | .... |
| 209... | 3 | 4,290,000 | 3.96 | 27.97 | 69.93 |
| | 4 | 19,600,000 | 5.10 | 4.59 | 90.30 |
| | 5 | 64,000,000 | 6.25 | 34.37 | 59.37 |
| | 6 | 275,000,000 | 2.90 | 67.63 | 29.45 |
| 211... | 0 | 21,000 | 4.76 | 52.38 | 42.85 |
| | 1 | .... | .... | .... | .... |
| | 2 | 2,060,000 | 13.10 | 4.36 | 82.52 |
| | 3 | 15,900,000 | 6.28 | 2.51 | 91.19 |
| | 4 | 60,000,000 | 5.00 | 43.33 | 51.66 |
| | 5 | 268,000,000 | 1.11 | 74.62 | 24.25 |
| 213... | 0 | 126,000 | 42.06 | 2.38 | 55.55 |
| | 1 | 17,000 | .... | 82.35 | 17.64 |
| | 2 | 210,000 | 4.76 | 95.23 | .... |
| | 3 | 14,000,000 | 28.57 | 21.42 | 50.00 |
| | 4 | 213,000,000 | .46 | 92.01 | 7.51 |
| 215... | 0 | 18,000 | 5.55 | 61.11 | 33.33 |
| | 1 | 40,000 | 55.00 | 7.50 | 37.50 |
| | 2 | 2,700,000 | 29.62 | 14.81 | 55.55 |
| | 3 | 33,000,000 | 12.12 | 60.60 | 27.27 |
| 217... | 0 | 5,900 | 6.77 | 25.42 | 67.79 |
| | 1 | 14,000 | 28.42 | 14.28 | 57.14 |
| | 2 | 3,100,000 | 32.25 | 29.03 | 38.71 |
| | 3 | 163,000,000 | .61 | 88.95 | 10.42 |
| 219... | 0 | 14,100 | 2.12 | 6.38 | 91.48 |
| | 1 | 87,000 | 16.09 | 3.44 | 80.45 |
| | 2 | 1,700,000 | 5.88 | 35.29 | 58.82 |
| 221... | 0 | 26,600 | 1.12 | 39.84 | 59.02 |
| | 1 | 1,170,000 | 9.40 | .85 | 89.74 |

**Table** XIII.—*Raw and pasteurized milk in New York City—Daily total bacterial counts and group percentages—Milk held at 10° C. (50° F.)*—Continued.

PASTEURIZED MILK—DAIRIES K AND M.

| Sample No. | Age of milk in days. | Total bacteria per c. c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|
| 225... | 0 | 531,000 | 0.18 | 64.03 | 35.78 |
|  | 1 | 440,000 | ([a]) | 84.09 | 15.90 |
|  | 2 | 1,600,000 | 18.75 | 50.00 | 31.25 |
|  | 3 | 24,000,000 | 16.66 | 16.66 | 66.66 |
|  | 4 | 114,000,000 | 3.50 | 64.03 | 32.45 |
|  | 5 | ...... | ...... | ...... | ...... |
|  | 6 | 880,000,000 | ([b]) | 94.31 | 5.68 |
| 227... | 0 | 31,500 | 6.04 | 9.76 | 84.18 |
|  | 1 | 68,000 | 14.70 | 26.47 | 58.82 |
|  | 2 | 2,300,000 | 30.43 | 21.73 | 47.82 |
| 229... | 0 | 34,000 | 23.52 | 32.35 | 44.11 |
|  | 1 | 120,000 | 5.00 | 87.50 | 7.5 |
|  | 2 | 15,000,000 | 20.00 | 13.33 | 66.66 |
| 231... | 0 | 25,300 | 1.97 | 26.83 | 71.14 |
|  | 1 | ...... | ...... | ...... | ...... |
|  | 2 | ...... | ...... | ...... | ...... |
|  | 3 | 120,000,000 | .83 | 70.83 | 28.33 |
| 233... | 0 | 36,700 | 2.17 | 31.88 | 65.94 |
|  | 1 | ...... | ...... | ...... | ...... |
|  | 2 | ...... | ...... | ...... | ...... |
|  | 3 | 151,000,000 | .72 | 79.41 | 19.85 |
| 235... | 0 | 17,000 | 8.23 | 16.47 | 75.29 |
|  | 1 | ...... | ...... | ...... | ...... |
| 235... | 2 | 2,400,000 | 16.66 | 4.16 | 79.16 |
|  | 3 | 3,300,000 | 18.18 | 9.09 | 72.72 |
| 237... | 0 | 16,500 | 1.81 | 60.60 | 37.52 |
|  | 1 | 1,610,000 | 5.59 | 40.37 | 54.03 |
|  | 2 | 10,000,000 | 2.00 | 74.00 | 24.00 |
| 239... | 0 | 25,400 | 82.67 | 11.80 | 5.11 |
|  | 1 | 12,400,000 | 32.25 | .80 | 66.92 |
|  | 2 | 5,840,000 | 4.10 | 90.75 | 51.36 |
|  | 3 | 52,000,000 | 15.38 | 57.69 | 26.92 |
| 241... | 0 | 13,400 | 6.71 | 21.64 | 71.64 |
|  | 1 | 950,000 | 13.68 | 6.31 | 80.00 |
|  | 2 | ...... | ...... | ...... | ...... |
|  | 3 | 109,000,000 | 17.43 | 58.71 | 23.75 |
| 243... | 0 | 6,700 | 17.91 | ...... | 82.09 |
|  | 1 | 160,000 | 6.25 | 6.25 | 87.50 |
|  | 2 | 2,400,000 | 20.83 | 12.50 | 66.66 |
|  | 3 | 62,000,000 | 3.22 | 38.70 | 58.06 |
| 245... | 0 | 8,000 | 47.50 | 2.50 | 50.00 |
|  | 1 | ...... | ...... | ...... | ...... |
|  | 2 | 3,000,000 | ...... | 10.00 | 90.00 |
|  | 3 | 39,000,000 | 20.51 | 35.89 | 43.58 |
|  | 4 | 38,000,000 | 28.94 | 18.42 | 52.63 |

CERTIFIED MILK.

| Sample No. | Age of milk in days. | Total bacteria per c. c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|
| 251... | 0 | 300 | ...... | ...... | 100.00 |
|  | 1 | ...... | ...... | ...... | ...... |
|  | 2 | 2,000 | 50.00 | ...... | 50.00 |
|  | 3 | 17,100,000 | 2.33 | ...... | 97.66 |
| 251... | 4 | 15,000,000 | 20.00 | ...... | 80.00 |
|  | 5 | 24,700,000 | 9.71 | ...... | 90.28 |
|  | 6 | ...... | ...... | ...... | ...... |
|  | 7 | 53,000,000 | 16.98 | 5.66 | 77.35 |

RAW MILK.

| Sample No. | Age of milk in days. | Total bacteria per c. c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|
| 253... | 0 | 148,000 | 4.72 | 84.45 | 10.81 |
|  | 1 | 1,440,000 | 4.16 | 93.05 | 2.77 |
|  | 2 | 6,000,000 | 66.66 | ...... | 33.33 |
|  | 3 | ...... | ...... | ...... | ...... |
|  | 4 | 15,000,000 | 20.00 | 60.00 | 20.00 |
| 261... | 0 | 44,100 | 2.49 | 77.09 | 20.40 |
|  | 1 | 630,000 | ...... | 80.95 | 19.04 |
|  | 2 | 4,300,000 | 27.90 | 44.18 | 27.90 |
|  | 3 | 61,000,000 | 11.47 | 60.65 | 27.86 |
|  | 4 | 122,000,000 | 12.29 | 51.63 | 36.06 |
| 255... | 0 | 32,000 | 37.50 | 34.37 | 28.12 |
|  | 1 | 130,000 | 23.07 | 23.07 | 53.84 |
|  | 2 | 5,100,000 | 25.49 | 7.84 | 66.66 |
|  | 3 | 146,000,000 | 3.42 | 61.64 | 34.93 |
|  | 4 | ...... | ...... | ...... | ...... |
|  | 5 | 125,000,000 | 17.60 | 44.80 | 37.50 |
| 257... | 0 | 170,000 | 17.64 | 47.05 | 35.29 |
|  | 1 | 200,000 | 10.00 | 75.00 | 15.00 |
|  | 2 | 5,550,000 | 49.09 | 1.81 | 49.09 |
|  | 3 | ...... | ...... | ...... | ...... |
|  | 4 | 60,000,000 | 25.00 | 11.66 | 63.33 |
|  | 5 | 86,000,000 | 32.55 | 12.79 | 54.65 |
| 259... | 0 | 580,000 | 8.62 | 87.93 | 3.44 |
|  | 1 | 4,000,000 | 32.50 | 17.50 | 50.00 |
|  | 2 | ...... | ...... | ...... | ...... |
|  | 3 | 21,900,000 | 9.13 | 51.14 | 39.72 |
|  | 4 | 114,000,000 | 15.78 | 48.24 | 35.96 |
| 263... | 0 | 21,100,000 | 13.27 | 2.36 | 84.36 |
|  | 1 | 102,000,000 | 7.84 | 35.29 | 56.86 |
|  | 2 | 159,000,000 | 10.69 | 33.33 | 55.97 |
|  | 3 | 229,000,000 | 3.93 | 62.44 | 33.62 |
| 265... | 0 | 315,000 | 4.12 | 88.25 | 7.61 |
|  | 1 | 730,000 | 23.28 | 35.61 | 41.09 |
|  | 2 | 7,500,000 | 48.00 | 13.33 | 38.66 |
|  | 3 | 40,000,000 | 57.50 | 10.00 | 32.50 |
|  | 4 | 79,000,000 | 31.64 | 25.31 | 43.03 |
| 267... | 0 | 40,000 | 5.00 | 42.50 | 52.50 |
|  | 1 | 430,000 | 18.60 | 37.20 | 44.18 |
|  | 2 | 7,100,000 | 32.39 | 4.22 | 63.38 |
|  | 3 | 39,000,000 | 38.46 | 25.64 | 35.89 |
| 269... | 0 | 67,000 | 32.83 | 46.26 | 20.89 |
|  | 1 | 1,400,000 | 7.14 | 35.71 | 57.14 |
|  | 2 | 79,000,000 | 15.18 | 41.77 | 43.03 |

[a] 0 in 10,000 dilutions.

[b] 0 in 100,000 dilutions.

TABLE XIV.—*Raw and pasteurized milk at New York City—Total daily bacterial counts and group percentages—Milk held at room temperature, 20° C. (68° F.).*

PASTEURIZED MILK—DAIRY H.

| Sample No. | Age of milk in days. | Total bacteria per c. c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|
| 202... | 0 | 8,600 | 3.48 | 47.67 | 48.83 |
| | 1 | 2,850,000 | 9.47 | .70 | 89.82 |
| | 2 | 417,000,000 | 1.67 | 50.35 | 47.96 |
| 204... | 0 | 20,600 | 2.91 | 9.70 | 87.37 |
| | 1 | 4,300,000 | 9.30 | 13.95 | 76.74 |
| 206... | 0 | 32,200 | 3.72 | 15.52 | 80.75 |
| | 1 | 15,500,000 | 8.38 | 56.17 | 35.48 |
| 208... | 0 | 8,700 | 2.29 | 11.49 | 86.20 |
| | 1 | ............ | ........ | ........ | ...... |
| | 2 | 201,000,000 | 2.98 | 63.18 | 33.83 |
| 212... | 0 | 29,000 | 1.72 | 46.55 | 51.72 |
| | 1 | ............ | ........ | ........ | ...... |
| | 2 | 400,000,000 | 2.50 | 75.00 | 22.50 |
| 214... | 0 | 14,800 | 1.35 | 2.02 | 96.62 |
| | 1 | 790,000 | 17.72 | 18.98 | 63.29 |
| | 2 | 254,000,000 | 1.57 | 86.61 | 11.81 |
| 216... | 0 | 7,300 | 4.10 | 41.09 | 54.79 |
| | 1 | 900,000 | 33.33 | 11.11 | 55.55 |
| | 2 | 312,000,000 | .96 | 89.42 | 9.61 |
| 218... | 0 | 132,000 | 4.54 | 28.78 | 66.66 |
| | 1 | 1,400,000 | 21.42 | 28.57 | 50.00 |
| 220... | 0 | 24,300 | 1.64 | 6.58 | 91.76 |
| | 1 | 16,300,000 | 9.20 | 7.36 | 83.43 |

PASTEURIZED MILK—DAIRIES K AND M.

| Sample No. | Age of milk in days. | Total bacteria per c. c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|
| 224... | 0 | ............ | ........ | ........ | ...... |
| | 1 | 571,000,000 | 0.17 | 99.82 | ...... |
| 226... | 0 | 543,000 | .55 | 99.44 | ...... |
| | 1 | 6,700,000 | 5.97 | 56.71 | 37.31 |
| 228... | 0 | 5,200 | 9.61 | 36.53 | 53.84 |
| | 1 | 15,900,000 | 1.69 | 89.83 | 8.47 |
| 230... | 0 | 32,400 | 1.54 | 4.32 | 94.13 |
| | 1 | 7,500,000 | 1.33 | 77.33 | 21.33 |
| 236... | 0 | 15,600 | 19.23 | 7.05 | 73.71 |
| 238... | 0 | 15,000 | 13.33 | 60.00 | 26.66 |
| | 1 | 35,100,000 | .85 | 67.23 | 31.90 |
| 240... | 0 | 5,400 | 16.66 | 7.40 | 75.92 |
| | 1 | 9,600,000 | 4.16 | 6.25 | 89.58 |
| 242... | 0 | 7,600 | 14.47 | 23.68 | 61.84 |
| | 1 | 73,000,000 | 4.10 | 30.13 | 65.75 |
| 244... | 0 | 20,200 | 27.22 | 1.98 | 70.79 |
| | 1 | 16,800,000 | 29.16 | 2.38 | 68.45 |
| 246... | 0 | 3,700 | 29.72 | 8.10 | 62.16 |
| | 1 | 12,700,000 | 3.93 | 28.34 | 67.71 |

CERTIFIED RAW MILK.

| Sample No. | Age of milk in days. | Total bacteria per c. c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|
| 252... | 0 | 200 | ........ | ........ | 100.00 |
| | 1 | 10,000 | ........ | ........ | 100.00 |
| 252... | 2 | 23,000,000 | 60.86 | 13.04 | 26.08 |
| | 3 | 481,000,000 | 2.91 | 65.90 | 31.18 |

RAW MILK.

| Sample No. | Age of milk in days. | Total bacteria per c. c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|
| 254... | 0 | 200,000 | 10.00 | 65.00 | 25.00 |
| | 1 | 40,000,000 | 17.50 | 50.00 | 32.50 |
| | 2 | 260,000,000 | 19.23 | 61.53 | 19.23 |
| 262... | 0 | 44,000 | 11.79 | 42.85 | 45.35 |
| | 1 | 218,000,000 | ........ | 94.49 | 5.50 |
| 256... | 0 | 45,000 | 33.33 | 42.22 | 24.44 |
| | 1 | 109,000,000 | 8.25 | 36.69 | 55.04 |
| 258... | 0 | 140,000 | 28.57 | 42.85 | 28.57 |
| | 1 | 14,700,000 | 21.76 | 34.01 | 44.21 |
| 260... | 0 | 240,000 | 9.16 | 79.16 | 11.66 |
| | 1 | 24,400,000 | 8.19 | 38.52 | 53.27 |
| 264... | 0 | 17,800,000 | 15.16 | 6.74 | 78.08 |
| 266... | 0 | 270,000 | 2.59 | 75.92 | 21.48 |
| | 1 | 70,000,000 | 24.28 | 51.42 | 24.28 |
| 268... | 0 | 18,000 | 11.11 | 33.33 | 55.55 |
| | 1 | 32,000,000 | 18.75 | 25.00 | 56.25 |
| 270... | 0 | 82,000 | 41.46 | 36.58 | 21.94 |
| | 1 | 164,000.000 | 9.14 | 53.04 | 37.80 |

TABLE XV.—*Raw milk at Washington, D. C., examined in January, 1909—Daily acidity and total and group counts of bacteria—Milk held at 10° C. (50° F.).*

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose gelatin. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 324 | 0 | 0.18 | 85,000 | 9,000 | 26,000 | 50,000 | Raw milk from dairy T. |
| | 1 | .23 | 30,800,000 | 1,500,000 | 9,900,000 | 19,400,000 | |
| | 2 | .19 | 28,800,000 | 5,900,000 | 3,800,000 | 19,100,000 | Temperature down to 4° C. (40° F.). |
| | 3 | .19 | 114,000,000 | 23,000,000 | 13,000,000 | 78,000,000 | |
| | 4 | .24 | 108,000,000 | 19,000,000 | 22,000,000 | 67,000,000 | Temperature low. |
| | 5 | .25 | 76,000,000 | 11,000,000 | 3,000,000 | 62,000,000 | Old taste. |
| | 6 | | | | | | |
| | 7 | .53 | 436,000,000 | 60,000,000 | 147,000,000 | 229,000,000 | |
| 325 | 0 | .16 | 43,400 | 10,000 | 13,900 | 19,500 | |
| | 1 | .18 | 660,000 | 50,000 | 280,000 | 330,000 | |
| | 2 | .16 | 1,590,000 | 430,000 | 150,000 | 1,010,000 | |
| | 3 | .17 | 5,500,000 | 2,700,000 | 300,000 | 2,500,000 | |
| | 4 | .18 | 24,000,000 | 3,700,000 | 1,300,000 | 19,000,000 | Do. |
| | 5 | | | | | | |
| | 6 | .63 | 475,000,000 | 67,000,000 | 200,000,000 | 208,000,000 | Sour; strong old flavor. |
| 326 | 0 | .18 | 30,700 | 2,100 | 8,100 | 20,500 | |
| | 1 | .16 | 400,000 | 110,000 | 50,000 | 240,000 | |
| | 2 | .16 | 840,000 | 310,000 | 40,000 | 490,000 | |
| | 3 | .16 | 910,000 | 350,000 | 30,000 | 530,000 | |
| | 4 | | | | | | |
| | 5 | .38 | 241,000,000 | 53,000,000 | 16,000,000 | 172,000,000 | Old taste; might be used. |
| | 6 | .58 | 563,000,000 | 32,000,000 | 394,000,000 | 137,000,000 | Old taste; sour; putrid. |
| | 7 | .69 | | | | | |
| 327 | 0 | .16 | 149,000 | 34,000 | 44,000 | 71,000 | |
| | 1 | .16 | 260,000 | 65,000 | 31,000 | 164,000 | |
| | 2 | .18 | 19,000,000 | 3,800,000 | 300,000 | 14,900,000 | |
| | 3 | | | | | | |
| | 4 | .40 | 411,000,000 | 90,000,000 | 200,000,000 | 121,000,000 | Old taste. |
| | 5 | .65 | 1,220,000,000 | 60,000,000 | 730,000,000 | 430,000,000 | Old taste; sour; would not be used. |
| | 6 | .73 | | | | | Curdled. |
| 328 | 0 | .14 | 126,000 | 34.000 | 55,000 | 37,000 | |
| | 1 | .16 | 17,900,000 | 5,800,000 | 4,900,000 | 7,200,000 | |
| | 2 | | | | | | |
| | 3 | .52 | 508,000,000 | 140,000,000 | 262,000,000 | 106,000,000 | Very slightly sour; would be used by many. |
| | 4 | .72 | | | | | Curdled. |
| 329 | 0 | .16 | 14,200 | 3,300 | 3,700 | 7,200 | |
| | 1 | | | | | | |
| | 2 | .22 | 116,000,000 | 36,000,000 | 20,000,000 | 60,000,000 | |
| | 3 | .29 | 240,000,000 | 9,000,000 | 192,000,000 | 39,000,000 | |
| | 4 | .45 | 404,000,000 | 75,000,000 | 207,000,000 | 122,000,000 | Old taste; slightly sour. |
| | 5 | .56 | | | | | Sour; not curdled. |
| | 6 | .68 | | | | | Old, putrid taste; sour. |
| 330 | 0 | .16 | 125,000 | 23,000 | 37,000 | 65,000 | |
| | 1 | .16 | 9,500,000 | 2,800,000 | 1,500,000 | 5,200,000 | |
| | 2 | .16 | 45,000,000 | 6,700,000 | 10,600,000 | 277,000 | Old taste. |
| | 3 | .20 | 213,000,000 | 50,000,000 | 47,000,000 | 116,000,000 | Old taste; cheesy. |
| | 4 | .40 | 820,000,000 | 140,000,000 | 330,000,000 | 350,000,000 | Old taste; would not be used. |
| | 5 | .61 | | | | | Sharp old taste; sour. |
| 331 | 0 | .15 | 523,000 | 35,000 | 275,000 | 213,000 | |
| | 1 | .16 | 8,900,000 | 2,800,000 | 1,500,000 | 4,600,000 | |
| | 2 | .15 | 79,000,000 | 14,000,000 | 27,000,000 | 38,000,000 | |
| | 3 | .25 | 84,000,000 | 13,000,000 | 38,000,000 | 33,000,000 | Slightly old taste. |
| | 4 | .36 | 226,000,000 | 53,000,000 | 56,000,000 | 117,000,000 | Old taste; sweetish. |
| | 5 | | | | | | |
| | 6 | .66 | | | | | Putrid; sour. |
| 332 | 0 | .16 | 627,000 | 159,000 | 148,000 | 320,000 | |
| | 1 | .16 | 21,000,000 | 2,300,000 | 9,100,000 | 9,600,000 | |
| | 2 | .21 | 92,000,000 | 19,000,000 | 32,000,000 | 41,000,000 | Slightly old taste. |
| | 3 | .30 | 184,000,000 | 31,000,000 | 75,000,000 | 78,000,000 | Do. |
| | 4 | | | | | | |
| | 5 | .63 | | | | | Bitter; sour. |

TABLE XV.—*Raw milk at Washington, D. C., examined in January, 1909—Daily acidity and total and group counts of bacteria—Milk held at 10° C. (50° F.)*—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose gelatin. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 333 | 0 | 0.15 | 172,000 | 15,000 | 58,000 | 99,000 | |
| | 1 | .17 | 7,000,000 | 2,300,000 | 600,000 | 4,100,000 | |
| | 2 | .18 | 53,000,000 | 13,000,000 | 9,000,000 | 31,000,000 | |
| | 3 | | | | | | |
| | 4 | .44 | 860,000,000 | 220,000,000 | 180,000,000 | 460,000,000 | Old taste; would not be used. |
| | 5 | .63 | 690,000,000 | 100,000,000 | 230,000,000 | 360,000,000 | Old taste; bitter; slightly sour. |
| | 6 | .74 | | | | | Old taste; sour. |
| 334 | 0 | .14 | 464,000 | 450,000 | 2,000 | 12,000 | |
| | 1 | .18 | 11,000,000 | 4,500,000 | 500,000 | 6,000,000 | |
| | 2 | | | | | | |
| | 3 | .27 | 123,000,000 | 68,000,000 | 8,000,000 | 47,000,000 | Old taste. |
| | 4 | .37 | 167,000,000 | 76,000,000 | 14,000,000 | 77,000,000 | Do. |
| | 5 | .54 | | | | | Sour; bitter. |
| 335 | 0 | .16 | 324,000 | 46,000 | 40,000 | 238,000 | |
| | 1 | | | | | | |
| | 2 | .18 | 123,000,000 | 22,000,000 | 25,000,000 | 76,000,000 | |
| | 3 | .30 | 194,000,000 | 30,000,000 | 74,000,000 | 90,000,000 | |
| | 4 | .41 | 150,000,000 | 26,000,000 | 62,000,000 | 62,000,000 | Old taste. |
| | 5 | .58 | | | | | Bitter; sour. |
| | 6 | .63 | | | | | Sour; old. |
| 336 | 0 | .16 | 243,000 | 40,000 | 75,000 | 128,000 | |
| | 1 | .16 | 3,810,000 | 670,000 | 1,170,000 | 1,970,000 | |
| | 2 | .18 | 47,900,000 | 5,500,000 | 7,700,000 | 34,700,000 | |
| | 3 | .21 | 190,000,000 | 30,000,000 | 80,000,000 | 80,000,000 | Slightly old taste. |
| | 4 | .37 | 182,000,000 | 33,000,000 | 43,000,000 | 106,000,000 | Slightly old taste; slightly putrid. |
| | 5 | | | | | | |
| | 6 | .65 | | | | | Strong, old taste; curdled. |
| 337 | 0 | .16 | 146,000 | 25,000 | 27,000 | 94,000 | |
| | 1 | .17 | 7,030,000 | 1,230,000 | 40,000 | 5,760,000 | Acid count probably low. |
| | 2 | .18 | 120,000 000 | 40,000,000 | 20,000.000 | 60,000,000 | |
| | 3 | .22 | 167,000,000 | 26,000,000 | 46,000,000 | 95,000,000 | |
| | 4 | | | | | | |
| | 5 | .64 | | | | | Strong, old taste; sour. |
| 338 | 0 | .17 | 36,000 | 5,200 | 9,400 | 21,400 | |
| | 1 | .16 | 3,700,000 | 1,000,000 | 400,000 | 2,300,000 | |
| | 2 | .19 | 37,000,000 | 15,000,000 | 6,000,000 | 16,000,000 | |
| | 3 | | | | | | |
| | 4 | .38 | 306,000,000 | 31,000,000 | 161,000,000 | 114,000,000 | Old taste. |
| | 5 | .63 | | | | | Sour. |
| 339 | 0 | .16 | 78,000 | 18,000 | 27,000 | 33,000 | |
| | 1 | .18 | 3,210,000 | 600,000 | 920,000 | 1,690,000 | |
| | 2 | | | | | | |
| | 3 | .31 | 143,000,000 | 9,000,000 | 49,000,000 | 85,000,000 | Old taste. |
| | 4 | .58 | 564,000,000 | 40,000,000 | 305,000,000 | 219,000,000 | Bitter. |
| | 5 | .65 | | | | | Sour. |
| 340 | 0 | .16 | 1,190,000 | 90,000 | 670,000 | 430,000 | |
| | 1 | | | | | | |
| | 2 | .24 | 152,000,000 | 11,000,000 | 59,000,000 | 82,000 000 | Very slightly old taste. |
| | 3 | .43 | 335,000,000 | 14,000,000 | 229,000,000 | 92,000,000 | Slightly sour. |
| | 4 | .65 | | | | | Sour. |
| 341 | 0 | .19 | 4,400 | 1,500 | 600 | 2,300 | Raw milk from dairy S. |
| | 1 | .21 | 50,000 | 15,000 | | 35,000 | |
| | 2 | .21 | 31,200,000 | 3,000,000 | | 28,200,000 | |
| | 3 | .20 | 34,000,000 | 7,000,000 | | 27,000,000 | |
| | 4 | | 200,000,000 | 60,000,000 | | 140,000,000 | |
| | 5 | .28 | 140,000,000 | 44,000,000 | 8,000,000 | 88,000,000 | |
| | 6 | | | | | | |
| | 7 | .50 | 410,000,000 | 150,000,000 | 70,000,000 | 190,000,000 | Curdled. |

**Table XV.**—*Raw milk at Washington, D. C., examined in January, 1909—Daily acidity and total and group counts of bacteria—Milk held at 10° C. (50° F.)*—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose gelatin. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 342 | 0 | 0.19 | 1,400 | 800 | 200 | 400 | |
| | 1 | .20 | 4,000 | 2,100 | 900 | 1,000 | |
| | 2 | .19 | 868,000 | 36,000 | ............ | 832,000 | |
| | 3 | ...... | 36,700,000 | 3,200,000 | ............ | 33,500,000 | |
| | 4 | .27 | 81,000,000 | 5,000,000 | ............ | 76,000,000 | |
| | 5 | ...... | ............ | ............ | ............ | ............ | |
| | 6 | .43 | 590,000,000 | 20,000,000 | 250,000,000 | 320,000,000 | |
| | 7 | .64 | ............ | ............ | ............ | ............ | |
| 343 | 0 | .19 | 67,000 | 29,000 | 4,000 | 34,000 | |
| | 1 | ...... | 8,200,000 | 1,700,000 | ............ | 6,500,000 | |
| | 2 | .21 | 27,700,000 | 5,000,000 | 200,000 | 22,500,000 | |
| | 3 | ...... | ............ | ............ | ............ | ............ | |
| | 4 | .25 | 292,000,000 | 14,000,000 | 111,000,000 | 167,000,000 | |
| | 5 | .45 | ............ | ............ | ............ | ............ | |
| | 6 | .64 | ............ | ............ | ............ | ............ | |
| 344 | 0 | ...... | 5,400 | 3,800 | 600 | 1,000 | |
| | 1 | .21 | 170,000 | 60,000 | ............ | 110,000 | |
| | 2 | ...... | ............ | ............ | ............ | ............ | |
| | 3 | .24 | 122,000,000 | 14,000,000 | 1,000,000 | 107,000,000 | |
| | 4 | .24 | ............ | ............ | ............ | ............ | |
| | 5 | .45 | ............ | ............ | ............ | ............ | |

**Table XVI.**—*Raw milk at Washington, D. C., examined during winter 1909-10—Daily total and group counts of bacteria and daily acidity—Milk held at room temperature, 20° C. (68° F.).*

| ample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose gelatin. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 345 | 0 | 0.16 | 39,000 | 5,000 | 10,000 | 24,000 | |
| | 1 | .20 | 140,000,000 | 60,000,000 | 20,000,000 | 60,000,000 | |
| | 2 | .63 | 500,000,000 | 12,000,000 | 425,000,000 | 63,000,000 | Curdled; not sour to taste. |
| 346 | 0 | .16 | 246,000 | 25,000 | 100,000 | 121,000 | |
| | 1 | .22 | 121,000,000 | 8,000,000 | 70,000,000 | 43,000,000 | |
| | 2 | .63 | 654,000,000 | 54,000,000 | 429,000,000 | 171,000,000 | Sour; putrid. |
| 347 | 0 | .16 | 102,000 | 15,000 | 17,000 | 70,000 | |
| | 1 | .18 | 69,000,000 | 11,000,000 | 5,800,000 | 52,200,000 | |
| | 2 | .63 | ............ | ............ | ............ | ............ | Sour; slightly curdled. |
| 348 | 0 | .16 | 40,800 | 8,400 | 16,100 | 16,300 | |
| | 1 | .22 | 73,000,000 | 4,000,000 | 51,000,000 | 18,000,000 | |
| | 2 | .66 | 72,000,000 | 7,000,000 | 31,000,000 | 34,000,000 | Sour; curdled. |
| 349 | 0 | .16 | 78,000 | 12,000 | 19,000 | 47,000 | |
| | 1 | .23 | ............ | ............ | ............ | ............ | |
| | 2 | ...... | ............ | ............ | ............ | ............ | |
| | 3 | .93 | ............ | ............ | ............ | ............ | Curdled. |
| 350 | 0 | .12 | 34,600 | 5,500 | 14,200 | 14,900 | |
| | 1 | .25 | 73,000,000 | 19,000,000 | 23,000,000 | 31,000,000 | |
| | 2 | .61 | 86,000,000 | 8,000,000 | 49,000,000 | 29,000,000 | |
| 351 | 0 | .17 | 372,000 | 21,000 | 267,000 | 84,000 | |
| | 1 | .24 | 168,000,000 | 22,000,000 | 100,000,000 | 46,000,000 | |
| | 2 | .72 | 1,070,000,000 | 60,000,000 | 800,000,000 | 210,000,000 | |

TABLE XVI.—*Raw milk at Washington, D. C., examined during winter 1909-10—Daily total and group counts of bacteria and daily acidity—Milk held at room temperature, 20° C. (68° F.)*—Continued.

| Sample No. | Age of milk in days. | Acidity in percentage of lactic acid. | Total bacteria per c. c. on litmus lactose gelatin. | Peptonizing bacteria per c. c. on litmus lactose gelatin. | Lactic-acid bacteria per c. c. on litmus lactose gelatin. | Alkali formers and inert bacteria per c. c. on litmus lactose gelatin. | Remarks. |
|---|---|---|---|---|---|---|---|
| 352 | 0 | 0.15 | 25,000 | 11,000 | 8,000 | 6,000 | |
| | 1 | .18 | 64,000,000 | 38,000,000 | 5,000,000 | 21,000,000 | Slightly strong taste. |
| | 2 | .61 | 416,000,000 | 71,000,000 | 121,000,000 | 224,000,000 | Putrid. |
| 353 | 0 | .17 | 19,700 | 3,000 | 4,100 | 12,600 | |
| | 1 | .20 | 70,000,000 | 10,000,000 | 18,000,000 | 42,000,000 | |
| | 2 | .63 | 349,000,000 | 49,000,000 | 130,000,000 | 170,000,000 | Sour; bitter. |
| 354 | 0 | .17 | 257,000 | 14,000 | 164,000 | 79,000 | |
| | 1 | .23 | 94,000,000 | 18,000,000 | 10,000,000 | 66,000,000 | Garlic taste. |
| 355 | 0 | .15 | 111,000 | 36,000 | 25,000 | 50,000 | |
| | 1 | | | | | | |
| | 2 | .58 | 700,000,000 | 80,000,000 | 190,000,000 | 430,000,000 | |
| 356 | 0 | .17 | 6,700 | 500 | 2,600 | 3,600 | |
| | 1 | .17 | 14,500,000 | 60,000,000 | 16,000,000 | 69,000,000 | |
| | 2 | .34 | 231,000,000 | 37,000,000 | 93,000,000 | 101,000,000 | Very slight old taste. |
| 357 | 0 | .16 | 20,800 | 1,300 | 5,300 | 14,200 | |
| | 1 | .18 | 29,200,000 | 8,400,000 | 9,100,000 | 11,700,000 | |
| | 2 | .52 | 271,000,000 | 25,000,000 | 126,000,000 | 120,000,000 | Slightly old taste. |
| 358 | 0 | .17 | 18,400 | 1,500 | 5,300 | 11,600 | |
| | 1 | .17 | 12,000,000 | 1,400,000 | 4,500,000 | 6,100,000 | |
| | 2 | .53 | 790,000,000 | 80,000,000 | 440,000,000 | 270,000,000 | Old taste. |
| 359 | 0 | .17 | 4,600 | (a) | 2,500 | 2,100 | |
| | 1 | .17 | 88,000,000 | 29,000,000 | 11,000,000 | 48,000,000 | |
| | 2 | .30 | 1,220,000,000 | 150,000,000 | 520,000,000 | 550,000,000 | Slightly sour. |
| 360 | 0 | .18 | 22,800 | 4,000 | 8,100 | 10,700 | |
| | 1 | .18 | 83,000.000 | 31.000.000 | 17,000,000 | 35,000,000 | |
| | 2 | .58 | 1,110,000,000 | 60,000,000 | 780,000,000 | 270,000,000 | Sour; old. |
| 361 | 0 | .18 | 24,900 | 4,000 | 5,700 | 15.200 | |
| | 1 | .21 | 123,000,000 | 24,000,000 | 31,000,000 | 68,000,000 | Slightly old taste. |
| | 2 | .67 | 1,010,000,000 | 60,000,000 | 750,000,000 | 200,000,000 | Curdled. |
| 362 | 0 | .15 | 130,000 | 2,000 | 45,000 | 83,000 | |
| | 1 | .24 | 111,000.000 | 15,000,000 | 41,000,000 | 55,000,000 | Old taste. |
| | 2 | .67 | 740,000,000 | 30,000,000 | 660,000,000 | 50,000,000 | Curdled. |
| 363 | 0 | .17 | 281,000 | 43.000 | 93,000 | 145,000 | |
| | 1 | .34 | 234,000,000 | 54,000,000 | 28.000,000 | 152,000,000 | Old. |
| | 2 | .76 | 139,000,000 | 30,000,000 | 48,000,000 | 61,000,000 | Curdled. |

[a] 0 in 100 dilution.

**TABLE XVII.**—*Raw milk at Washington, D. C.—Daily total counts and group percentages of bacteria—Milk held at 10° C. (50° F.).*

RAW MILK—DAIRY T.

| Sample No. | Age of milk in days. | Total bacteria per c. c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|
| 324 | 0 | 85,000 | 10.58 | 30.58 | 58.82 |
| | 1 | 30,800,000 | 4.87 | 32.14 | 62.98 |
| | 2 | 28,800,000 | 20.48 | 13.19 | 66.31 |
| | 3 | 114,000,000 | 20.17 | 11.40 | 68.42 |
| | 4 | 108,000,000 | 17.59 | 20.37 | 62.03 |
| | 5 | 76,000,000 | 14.47 | 3.94 | 81.57 |
| | 6 | ........ | ........ | ........ | ........ |
| | 7 | 436,000,000 | 13.76 | 33.71 | 52.52 |
| 325 | 0 | 43,400 | 23.04 | 32.02 | 44.93 |
| | 1 | 660,000 | 7.57 | 42.42 | 50.00 |
| | 2 | 1,590,000 | 27.04 | 9.43 | 63.52 |
| | 3 | 5,500,000 | 49.09 | 5.45 | 45.45 |
| | 4 | 24,000,000 | 15.41 | 5.41 | 79.16 |
| | 5 | ........ | ........ | ........ | ........ |
| | 6 | 475,000,000 | 14.10 | 42.10 | 43.78 |
| 326 | 0 | 30,700 | 6.84 | 26.38 | 66.77 |
| | 1 | 400,000 | 27.50 | 12.50 | 60.00 |
| | 2 | 840,000 | 36.90 | 4.76 | 58.33 |
| | 3 | 910,000 | 38.46 | 3.29 | 58.24 |
| | 4 | ........ | ........ | ........ | ........ |
| | 5 | 241,000,000 | 21.99 | 6.63 | 71.36 |
| | 6 | 563,000,000 | 5.68 | 69.98 | 24.33 |
| 327 | 0 | 149,000 | 22.81 | 29.53 | 47.65 |
| | 1 | 260,000 | 25.00 | 11.92 | 63.07 |
| | 2 | 19,000,000 | 20.00 | 1.57 | 78.42 |
| | 3 | ........ | ........ | ........ | ........ |
| | 4 | 411,000,000 | 21.89 | 48.66 | 29.44 |
| | 5 | 1,220,000,000 | 4.91 | 59.83 | 35.24 |
| 328 | 0 | 126,000 | 26.98 | 43.65 | 29.36 |
| | 1 | 17,900,000 | 32.40 | 27.37 | 40.22 |
| | 2 | ........ | ........ | ........ | ........ |
| | 3 | 508,000,000 | 27.55 | 51.57 | 20.86 |
| 329 | 0 | 14,200 | 23.23 | 26.03 | 50.70 |
| | 1 | ........ | ........ | ........ | ........ |
| | 2 | 116,000,000 | 31.03 | 17.24 | 51.72 |
| | 3 | 240,000,000 | 3.75 | 80.00 | 16.25 |
| | 4 | 404,000,000 | 18.56 | 51.23 | 30.19 |
| 330 | 0 | 125,000 | 18.40 | 29.60 | 52.00 |
| | 1 | 9,500,000 | 29.47 | 15.78 | 54.73 |
| | 2 | 45,000,000 | 14.88 | 23.55 | 61.55 |
| | 3 | 213,000,000 | 23.47 | 22.06 | 54.46 |
| | 4 | 820,000,000 | 17.07 | 40.24 | 42.68 |
| 331 | 0 | 523,000 | 6.69 | 52.58 | 40.72 |
| | 1 | 8,900,000 | 31.46 | 16.85 | 51.68 |
| | 2 | 79,000,000 | 17.72 | 34.17 | 48.10 |
| | 3 | 84,000,000 | 15.47 | 45.23 | 39.28 |
| | 4 | 226,000,000 | 23.45 | 24.77 | 51.76 |
| 332 | 0 | 627,000 | 25.35 | 23.60 | 51.03 |
| | 1 | 21,000,000 | 10.95 | 43.33 | 45.71 |
| | 2 | 92,000,000 | 20.65 | 34.78 | 44.56 |
| | 3 | 184,000,000 | 16.84 | 40.76 | 42.39 |
| 333 | 0 | 172,000 | 8.72 | 33.72 | 57.55 |
| | 1 | 7,000,000 | 32.85 | 8.57 | 58.57 |
| | 2 | 53,000,000 | 24.52 | 16.98 | 58.49 |
| | 3 | ........ | ........ | ........ | ........ |
| | 4 | 860,000,000 | 25.58 | 20.93 | 53.48 |
| | 5 | 690,000,000 | 14.49 | 33.33 | 52.17 |
| 334 | 0 | 464,000 | 96.98 | .43 | 2.58 |
| | 1 | 1,100,000 | 40.90 | 4.54 | 54.54 |
| | 2 | ........ | ........ | ........ | ........ |
| | 3 | 123,000,000 | 45.28 | 6.50 | 38.21 |
| | 4 | 167,000,000 | 45.50 | 8.38 | 46.10 |
| 335 | 0 | 324,000 | 14.19 | 12.34 | 73.45 |
| | 1 | ........ | ........ | ........ | ........ |
| | 2 | 123,000,000 | 17.88 | 20.32 | 61.78 |
| | 3 | 194,000,000 | 15.46 | 38.14 | 46.39 |
| | 4 | 150,000,000 | 17.33 | 41.33 | 41.33 |
| 336 | 0 | 243,000 | 16.46 | 30.86 | 52.67 |
| | 1 | 3,810,000 | 17.58 | 30.70 | 51.70 |
| | 2 | 47,900,000 | 11.48 | 16.07 | 72.44 |
| | 3 | 190,000,000 | 15.78 | 42.10 | 42.10 |
| | 4 | 182,000,000 | 18.13 | 23.62 | 58.24 |
| 337 | 0 | 146,000 | 17.12 | 18.49 | 64.38 |
| | 1 | 7,030,000 | 17.49 | .56 | 81.93 |
| | 2 | 120,000,000 | 33.33 | 16.66 | 50.00 |
| | 3 | 167,000,000 | 15.56 | 27.54 | 56.88 |
| 338 | 0 | 36,000 | 14.44 | 26.11 | 59.44 |
| | 1 | 3,700,000 | 27.02 | 10.81 | 62.16 |
| | 2 | 37,000,000 | 40.54 | 16.21 | 43.24 |
| | 3 | ........ | ........ | ........ | ........ |
| | 4 | 306,000,000 | 10.13 | 52.61 | 37.25 |
| 339 | 0 | 78,000 | 23.07 | 34.61 | 42.30 |
| | 1 | 3,210,000 | 18.69 | 28.66 | 52.64 |
| | 2 | ........ | ........ | ........ | ........ |
| | 3 | 143,000,000 | 6.29 | 34.26 | 59.44 |
| | 4 | 564,000,000 | 7.09 | 54.07 | 38.82 |
| 340 | 0 | 1,190,000 | 7.56 | 56.30 | 36.13 |
| | 1 | ........ | ........ | ........ | ........ |
| | 2 | 152,000,000 | 7.23 | 38.81 | 53.94 |
| | 3 | 335,000,000 | 4.17 | 68.35 | 27.46 |

**Table XVII.**—*Raw milk at Washington, D. C.—Daily total counts and group percentages of bacteria—Milk held at 10° C. (50° F.)*—Continued.

CLEAN MILK—DAIRY 8.

| Sample No. | Age of milk in days. | Total bacteria per c. c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|
| 341 | 0 | 4,400 | 34.09 | 13.63 | 52.27 |
| | 1 | 50,000 | 30.00 | ....... | 70.00 |
| | 2 | 31,200,000 | 9.61 | ....... | 90.38 |
| | 3 | 34,000,000 | 20.58 | ....... | 79.41 |
| | 4 | 200,000,000 | 30.00 | ....... | 70.00 |
| | 5 | 140,000,000 | 31.42 | 5.71 | 62.85 |
| | 6 | | | | |
| | 7 | 410,000,000 | 36.58 | 17.07 | 46.34 |
| 342 | 0 | 1,400 | 57.14 | 14.28 | 28.57 |
| | 1 | 4,000 | 52.50 | 22.50 | 25.00 |
| | 2 | 868,000 | 4.14 | ....... | 95.85 |
| | 3 | 36,700,000 | 8.71 | ....... | 91.28 |
| | 4 | 81,000,000 | 6.17 | ....... | 93.82 |
| | 5 | | | | |
| | 6 | 590,000,000 | 3.38 | 42.37 | 54.23 |
| 343 | 0 | 67,000 | 43.28 | 5.97 | 50.74 |
| | 1 | 8,200,000 | 20.73 | ....... | 79.26 |
| | 2 | 27,700,000 | 18.05 | .72 | 81.22 |
| | 3 | | | | |
| | 4 | 292,000,000 | 4.79 | 38.01 | 57.19 |
| 344 | 0 | 5,400 | 70.37 | 11.11 | 18.51 |
| | 1 | 170,000 | 35.29 | ....... | 64.70 |
| | 2 | | | | |
| | 3 | 122,000,000 | 11.47 | .81 | 87.70 |

**Table XVIII.**—*Raw milk at Washington, D. C.—Daily total counts and group percentages of bacteria—Milk held at room temperature, 20° C. (68° F.).*

| Sample No. | Age of milk in days. | Total bacteria per c. c. on litmus lactose gelatin. | Percentage of peptonizing bacteria. | Percentage of lactic-acid bacteria. | Percentage of alkali or inert bacteria. |
|---|---|---|---|---|---|
| 345 | 0 | 39,000 | 12.82 | 25.64 | 61.53 |
| | 1 | 140,000,000 | 42.85 | 14.28 | 42.85 |
| | 2 | 500,000,000 | 2.40 | 85.00 | 12.60 |
| 346 | 0 | 246,000 | 10.16 | 40.65 | 49.18 |
| | 1 | 121,000,000 | 6.61 | 57.85 | 35.53 |
| | 2 | 654,000,000 | 8.25 | 65.59 | 26.14 |
| 347 | 0 | 102,000 | 14.70 | 16.66 | 68.62 |
| | 1 | 69,000,000 | 15.94 | 8.40 | 75.65 |
| 348 | 0 | 40,800 | 20.58 | 39.46 | 39.95 |
| | 1 | 73,000,000 | 5.47 | 69.86 | 24.65 |
| | 2 | 72,000,000 | 9.72 | 43.05 | 47.22 |
| 349 | 0 | 78,000 | 15.38 | 24.35 | 60.25 |
| 350 | 0 | 34,600 | 15.38 | 41.04 | 43.06 |
| | 1 | 73,000,000 | 26.02 | 31.50 | 42.46 |
| | 2 | 86,000,000 | 9.30 | 56.97 | 33.72 |
| 351 | 0 | 372,000 | 5.64 | 71.77 | 22.58 |
| | 1 | 168,000,000 | 13.09 | 59.52 | 27.38 |
| | 2 | 1,070,000,000 | 5.60 | 74.76 | 19.62 |
| 352 | 0 | 25,000 | 44.00 | 32.00 | 24.00 |
| | 1 | 64,000,000 | 59.37 | 7.81 | 32.82 |
| | 2 | 416,000,000 | 17.06 | 29.08 | 53.84 |
| 353 | 0 | 19,700 | 15.22 | 20.81 | 63.95 |
| | 1 | 70,000,000 | 14.28 | 25.71 | 60.00 |
| | 2 | 349,000,000 | 14.04 | 37.24 | 48.71 |
| 354 | 0 | 257,000 | 5.44 | 63.81 | 30.73 |
| | 1 | 94,000,000 | 19.14 | 10.63 | 70.22 |
| 355 | 0 | 111,000 | 32.43 | 22.52 | 45.04 |
| | 1 | | | | |
| | 2 | 700,000,000 | 11.42 | 27.14 | 61.42 |
| 356 | 0 | 6,700 | 7.46 | 38.80 | 53.73 |
| | 1 | 14,500,000 | 41.37 | 11.03 | 47.58 |
| | 2 | 231,000,000 | 16.01 | 40.25 | 43.72 |
| 357 | 0 | 20,800 | 6.25 | 25.48 | 68.26 |
| | 1 | 29,200,000 | 28.76 | 31.16 | 40.06 |
| | 2 | 271,000,000 | 9.22 | 46.49 | 44.28 |
| 358 | 0 | 18,400 | 8.15 | 28.80 | 63.04 |
| | 1 | 12,000,000 | 11.66 | 37.50 | 50.83 |
| | 2 | 790,000,000 | 10.12 | 55.69 | 34.17 |
| 359 | 0 | 4,600 | ....... | 54.34 | 45.65 |
| | 1 | 88,000,000 | 32.95 | 12.50 | 54.54 |
| | 2 | 1,220,000,000 | 12.29 | 42.62 | 45.08 |
| 360 | 0 | 22,800 | 17.54 | 35.52 | 46.92 |
| | 1 | 83,000,000 | 37.34 | 20.48 | 42.16 |
| | 2 | 1,110,000,000 | 5.40 | 70.27 | 34.32 |
| 361 | 0 | 24,900 | 16.06 | 22.89 | 61.04 |
| | 1 | 123,000,000 | 19.51 | 25.19 | 55.28 |
| | 2 | 1,010,000,000 | 5.94 | 74.25 | 19.80 |
| 362 | 0 | 130,000 | 1.53 | 34.61 | 63.84 |
| | 1 | 111,000,000 | 13.51 | 36.93 | 49.54 |
| | 2 | 740,000,000 | 4.05 | 89.18 | 6.75 |
| 363 | 0 | 281,000 | 15.30 | 33.09 | 51.60 |
| | 1 | 234,000,000 | 23.07 | 11.96 | 64.95 |
| | 2 | 139,000,000 | 21.58 | 34.53 | 43.88 |

O

1.26
1.58

Issued May 18, 1911.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF ANIMAL INDUSTRY.—BULLETIN 127.

A. D. MELVIN, CHIEF OF BUREAU.

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# THE NEMATODES PARASITIC IN THE ALIMENTARY TRACT OF CATTLE, SHEEP, AND OTHER RUMINANTS.

BY

B. H. RANSOM, PH. D.,
*Chief of the Zoological Division.*

WASHINGTON:
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1911.

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# LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
*Washington, D. C., September 23, 1910.*

Sir: I have the honor to transmit herewith, and to recommend for publication as a bulletin of this Bureau, a manuscript entitled "The Nematodes Parasitic in the Alimentary Tract of Cattle, Sheep, and Other Ruminants," by Dr. B. H. Ransom, chief of the Zoological Division of this Bureau. The purpose of the paper is to supply data heretofore unpublished or otherwise not readily available, which will enable zoologists, veterinarians, and other investigators to identify nematodes belonging to known species that may be found in the alimentary tract of ruminants. All of the parasites in question, among which are included such important forms as the stomach worms, hookworms, and nodular worms, are briefly described, and the illustrations show the characteristics of the more important species.

Respectfully,

A. D. Melvin,
*Chief of Bureau.*

Hon. James Wilson,
*Secretary of Agriculture.*

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# THE NEMATODES PARASITIC IN THE ALIMENTARY TRACT OF CATTLE, SHEEP, AND OTHER RUMINANTS.

## INTRODUCTION.

Parasites belonging to the group known to zoologists as Nematoda[a] are so common in the alimentary tract of cattle, sheep, and other ruminants, and in many instances are so injurious, that the proper identification of the various species is a matter of considerable importance. Obviously, one of the first steps in the study of parasitic diseases is to determine the particular parasites concerned—to be able to recognize the different species and to distinguish them from one another.

In the present paper an attempt has been made to describe the various species of nematodes occurring in the alimentary tract of ruminants in sufficient detail so that any nematodes belonging to known species which may be found in that location can be identified by comparing the specimens with the descriptions herein. For complete references to the literature cited the reader may consult Bureau of Animal Industry Bulletion 39, Index-Catalogue of Medical and Veterinary Zoology.

## LIST OF NEMATODES OCCURRING IN THE ALIMENTARY TRACT OF RUMINANTS.[b]

The following list contains about 50 species of nematodes which have been reported as parasitic in the alimentary tract of ruminants, and not less than 30 of these are known to occur in this country. The portion of the alimentary canal in which each species is most commonly located (so far as it has been possible to determine) is mentioned, and if a species has been reported as a parasite of domestic cattle, sheep, or goats the fact is stated.

Family Ascaridæ:
  Genus *Ascaris*—
    *Ascaris vitulorum*.—Small intestine; cattle.
    [c] **Ascaris ovis*.—Small intestine; sheep.

---

[a] All parasitic worms with unjointed elongated cylindrical bodies, with a more or less firm cuticle composed of chitin, and with a terminal mouth at one end of the body and an anal opening terminal or subterminal at the other end, belong in the order Nematoda.

[b] *Gaigeria pachyscelis* should be added to this list. See Addendum, p. 124.

[c] The asterisk (*) denotes that specimens of the species indicated (collected in the United States) were examined by the author.

- Family Strongylidæ:
  - Subfamily Strongylinæ—
    - Genus _Agriostomum_—
      - _Agriostomum vryburgi_.—Small intestine; cattle (_Bos indicus_).
    - [a] Genus _Monodontus_—
      - *_Monodontus trigonocephalus_.—Small intestine; sheep, goat.
      - *_Monodontus phlebotomus_.—Small intestine; cattle.
      - _Monodontus longecirratus_.—Intestine.
    - Genus _Chabertia_—
      - *_Chabertia ovina_.—Large intestine; sheep, goat.
    - Genus _Eucyathostomum_—
      - _Eucyathostomum longesubulatum_.—Large intestine.
      - _Eucyathostomum spinulosum_.—Intestine.
    - Genus _Œsophagostomum_—
      - *_Œsophagostomum columbianum_.—Large intestine; sheep, goat, ?cattle.
      - *_Œsophagostomum radiatum_.—Large intestine; cattle.
      - *_Œsophagostomum venulosum_.—Large intestine; goat, sheep.
  - [a] Subfamily Metastrongylinæ—
    - Genus _Hæmonchus_—
      - *_Hæmonchus contortus_.—Fourth stomach; cattle, sheep, goat.
      - _Hæmonchus longistipes_ —Fourth stomach.
      - (?_Hæmonchus_) _bispinosus_.—Stomach.
    - Genus _Ostertagia_—
      - *_Ostertagia ostertagi_.—Fourth stomach; cattle.
      - *_Ostertagia circumcincta_.—Fourth stomach; sheep, goat.
      - *_Ostertagia trifurcata_.—Fourth stomach; sheep, goat.
      - *_Ostertagia marshalli_.—Fourth stomach; sheep.
      - *_Ostertagia occidentalis_.—Fourth stomach; sheep.
      - *_Ostertagia mentulata_.—Fourth stomach.
      - _Ostertagia brigantiaca_.—Small intestine.
    - Genus _Cooperia_—
      - *_Cooperia curticei_.—Small intestine; sheep, goat.
      - *_Cooperia punctata_.—Small intestine; cattle.
      - *_Cooperia oncophora_.—Small intestine; cattle, sheep, goat.
      - *_Cooperia pectinata_.—Fourth stomach; cattle.
    - Genus _Nematodirus_—
      - *_Nematodirus filicollis_.—Small intestine; cattle, sheep, goat.
      - _Nematodirus spathiger_.—Small intestine.
      - _Nematodirus digitatus_.—Stomach; cattle (_Bos indicus_).
    - Genus _Trichostrongylus_—
      - *_Trichostrongylus instabilis_.—Small intestine; sheep, goat.
      - _Trichostrongylus colubriformis_.—Small intestine; sheep.
      - *_Trichostrongylus probolurus_.—Small intestine; sheep.
      - *_Trichostrongylus vitrinus_.—Small intestine; sheep, goat.
      - *_Trichostrongylus extenuatus_.—Fourth stomach; cattle, sheep, goat.
      - *_Trichostrongylus capricola_.—Small intestine or fourth stomach; sheep, goat.
    - Species of uncertain generic position—
      - _Strongylus ventricosus_.—Small intestine.
      - _Strongylus fordii_.—Stomach or intestine; cattle.
- Family Filariidæ:
  - Genus _Gongylonema_—
    - *_Gongylonema scutatum_.—Mucous lining of esophagus; cattle, sheep, goat.
    - _Gongylonema verrucosum_.—Stomach; sheep, cattle (_Bos indicus_).
  - Genus _Spiroptera_—
    - _Spiroptera verrucosa_.—Stomach.

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[a] See Addendum, p. 124.

Family Angiostomidæ:
    Genus *Strongyloides*—
        **Strongyloides papillosus*.—Small intestine; sheep, goat.
        **Strongyloides ovocinctus*.—Small intestine.
Family Trichinellidæ:
  Subfamily Trichurinæ—
    Genus *Trichuris*—
        **Trichuris ovis*.—Large intestine; cattle, sheep, goat.
        *Trichuris discolor*.—?Stomach; cattle (*Bos indicus*).
        *Trichuris alcocki*.—(?Large) intestine.
        *Trichuris globulosa*.—?Large intestine.
        *Trichuris cameli*.—Large intestine.
        *Trichuris giraffæ*.—Small intestine.
    Genus *Capillaria*—
        **Capillaria brevipes*.—Small intestine; sheep.
        **Capillaria longipes*.—Small intestine; sheep.
        *Capillaria bovis*.—Small intestine; cattle.
  Subfamily Trichinellinæ—
    Genus *Trichinella*—
        *Trichinella spiralis*.—Small intestine; accidental in ruminants.

## METHODS OF COLLECTING AND PREPARING SPECIMENS.

Though some species of nematodes infesting ruminants may be recognized at a glance with a fair degree of certainty, for example such forms as *Hæmonchus contortus* and *Chabertia ovina*, other species require careful microscopical examination for their identification, either because of their small size or because in their grosser characters several species may look so much alike that they can only be distinguished from each other by means of the finer details of their structure. For the purpose of identification freshly collected specimens may be examined alive in physiological salt solution (about 6 grams of salt to a liter of water) on a glass slide under the microscope, but when time is lacking and if it is desired to retain specimens for future reference it is necessary that they be preserved for later examination.

Owing to the tedious nature of the task of picking out specimens one by one from the viscera of animals examined for parasites and the difficulty of finding nematodes, even those of considerable size, amid the ingesta of the alimentary tract, a more rapid and certain method of collection is desirable. A very satisfactory method consists in taking the various portions of the alimentary canal, opening them with an enterotome or other scissors of convenient size, and evacuating their contents into tall jars of water, washing and scraping their mucous lining in order to detach any adherent parasites. The contents of the jars are stirred up and then allowed to settle for a few minutes, during which time the worms, if any be present, settle toward the bottom together with the heavier ingesta. Then the contents of the jars except a few inches at the bottom are carefully decanted off, more water is added, and the same procedure repeated. This operation is continued until the liquid no longer becomes turbid when the contents of the jars are stirred. The water is poured off as before and physiological salt solution added. In this solution the worms may remain for several hours without being damaged. Poured out into a shallow dish the worms thus treated are readily seen and may be picked out with comparative ease from the ingesta.

The most satisfactory method of preservation for general purposes is that recommended by Looss (1901a).[a] The worms are killed in hot, nearly boiling, 70 per cent alcohol, to which may be added, if desired, 5 per cent of glycerin, or 10 per cent if the worms are small and readily permeated by the killing fluid. To prepare them for study the specimens may then be placed in a mixture of 20 parts of absolute alcohol and 80 parts of carbolic acid, which renders them sufficiently transparent for examination in temporary mounts under the microscope. As an alternative the specimens, if not already in glycerinated alcohol, may be placed in 5 to 10 per cent glycerin in alcohol and left uncovered in a warm, dry place, free from dust, until the alcohol has evaporated, after which more glycerin may be added, if necessary, to cover the specimens. This gradual change by evaporation from alcohol to glycerin prevents the ruinous shrinkage which would result by more abrupt changes from a medium of one specific gravity to one of another, and which commonly results when the usual technical methods are followed. The specimens may then be mounted in glycerin or in glycerin jelly for microscopical examination. As Looss (1901a) has pointed out, glycerin jelly or glycerin is, as a rule, a better mounting medium for nematodes than balsam, which renders specimens so transparent that many details of structure are not visible, or only difficultly so.

## STRUCTURE OF NEMATODES PARASITIC IN THE ALIMENTARY TRACT OF RUMINANTS.

In the following brief review of the anatomy of nematodes parasitic in the alimentary tract of ruminants those details of structure which are of practical importance in determining species are discussed in a general way.

### FORM.

As indicated by their name, the nematodes are more or less threadlike in form. They are elongated, cylindrical, usually attenuated toward one or both extremities. In the genus *Trichuris* the anterior portion of the body is much more slender than the posterior portion, and from their fancied resemblance to a whip the worms of that genus are commonly known as whip-worms.

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[a] The references are to the Index-Catalogue of Medical and Veterinary Zoology, published as Bulletin 39, Bureau of Animal Industry, Department of Agriculture.

### SIZE.

In size the adult nematodes infesting the alimentary tract of ruminants range from a length of about 3 mm. and a thickness of 50$\mu$ or less in the smallest species to a length of 25 cm. and a thickness of 5 mm. or more in the largest species. The majority of the species are forms less than 20 mm. in length and ½ mm. in thickness. *Ascaris vitulorum* (p. 25) is the largest species, while *Trichostrongylus extenuatus* (p. 94) and the two species of *Strongyloides* (p. 104) share the distinction of being the smallest. The females of each species, as is commonly the case with nematodes, are usually larger than the males, both in length and in thickness.

### CUTICLE.

The chitinous cuticle which forms the covering of the body varies in thickness, as a rule, according to the size of the worms. The layer of hypodermis which underlies the cuticle is thickened in the dorsal and ventral median lines, and in the lateral lines. These lines are especially conspicuous in the genus *Ascaris*. The excretory vessels are located in the lateral lines. These vessels unite near the head and open on the ventral surface of the body through an unpaired excretory pore (*e. p.*, fig. 2). Besides the median and lateral longitudinal lines the cuticle may be marked with other longitudinal lines, very narrow, in some instances (genus *Cooperia*) resembling rows of little dots. In the genus *Trichuris* the cuticle on the ventral surface is modified to form the so-called bacillary band, consisting of a mass of small rod-like structures perpendicular to the surface and projecting as little points. In the genus *Capillaria* similar bands may also be present in the lateral and dorsal lines. The cuticle in many cases is transversely striated. In the genus *Gongylonema* the cuticle in the anterior portion of the body bears numerous small shields or tubercles (fig. 119). The cuticle on the head and in the cervical region may be inflated in certain species, giving that portion of the body a swollen appearance (*c. i.*, figs. 24, 29). Narrow cuticular membranes or wings may be present attached along the longitudinal lines, sometimes extending the entire length of the body (*l. m.*, fig. 19). In *Gongylonema verrucosum* such a membrane is also present in the dorsal line. Cervical papillæ (*c. p.*, figs. 19, 34), are commonly present in the neck region, one in each lateral line. A transverse cervical groove on the ventral surface in the neighborhood of the excretory pore is a rather prominent feature of the genera *Chabertia* and *Œsophagostomum* (*c. g.*, figs. 12, 19).

Shedding of the cuticle, preceded by the formation of a new cuticle inside the old, is a characteristic of the growth and development of nematodes from the embryonic to the adult stage. One of the species considered in the present paper (*Strongyloides ovocinctus*, p. 108), apparently undergoes successive molts in the adult stage, the cast-off skins serving as egg cases.

### DIGESTIVE SYSTEM.

The digestive system is simple, consisting of a terminal mouth at the anterior end of the body, an esophagus, and a tubular straight intestine terminating in an anus which is either terminal at the posterior end of the body, or subterminal, on the ventral surface of the body near the posterior end.

#### MOUTH.

The mouth is very small in some species and relatively very large in others. The species with small mouths have small heads (figs. 34, 65) and those with large mouths, large heads (figs. 2, 12). In the family Ascaridæ the mouth is supplied with three large lips. The head may be provided with circum-oral papillæ; in the family Strongylidæ these are usually, if not always, 6 in number, 2 lateral and 4 submedian; they are frequently inconspicuous in species with small heads. The cuticle surrounding the mouth, as for example in *Œsophagostomum*, may be inflated, forming an annular mouth collar (*m. c.*, fig. 19). The genus *Chabertia* is characterized by a double crown of small, pointed chitinous denticles bordering the mouth (fig. 12). In *Œsophagostomum* and *Eucyathostomum* the mouth is provided with one or two crowns of slender leaf-like processes attached to its chitinous frame work and projecting radially inward and forward. In the genus *Hæmonchus* the small mouth is supplied with a tiny lancet. Some of the large-mouthed forms have teeth inside the buccal capsule (figs. 2, 7), and in one species, *Agriostomum vryburgi*, the anterior border of the mouth bears 8 strong recurved teeth projecting inward.

#### ESOPHAGUS.

In the Trichinellidæ the esophagus is very long, consisting of a cord of cells placed end to end in a single row pierced through the center by a continuous lumen. In the other families the adults all possess a muscular esophagus (*es.*, fig. 2), usually claviform, gradually enlarged posteriorly. The free-living generation of the genus *Strongyloides* is characterized by an esophagus with a posterior bulb (*b.*, fig. 133) which contains a masticatory apparatus in its interior. This is a common characteristic of the first larval stage of the Strongylidæ, but none of the adult nematodes parasitic in the alimentary tract of ruminants so far as known possesses an esophagus of this type.

### INTESTINE.

The intestine is of little importance from the standpoint of classification. In the male it unites at its posterior end with the vas deferens to form a cloaca whose opening serves the double purpose of a genital pore and anus.

### ANUS.

The anus of the female is usually removed some distance from the posterior end of the body (*an.*, fig. 5). The length and shape of the postanal region, which may be termed the tail, are important characters in distinguishing the females of closely related species from one another. In the family Trichinellidæ the anus is practically terminal in both sexes. The anus of the males of the family Strongylidæ is terminal or almost terminal. In the Ascaridæ and Filariidæ the males are supplied with papillæ in the neighborhood of the anus, some preanal, some postanal, which are of importance in classification (fig. 129).

### NERVOUS SYSTEM.

A nerve ring (*n. r.*, fig. 2) whose location varies somewhat in different species surrounds the esophagus usually near its middle.

### REPRODUCTIVE SYSTEM.

The sexes are always separate except possibly in the parasitic generation of the genus *Strongyloides*. In this genus there is a free-living sexual generation consisting of males and females, but the parasitic generation consists only of egg-producing individuals somewhat different in structure from the females of the free-living generation. Though these individuals may be interpreted as hermaphroditic forms, they are more likely true parthenogenetic females, whose eggs develop without fertilization.

The genital glands and ducts of nematodes are tubular, very long and much coiled and twisted, loosely attached in the body cavity and comprising most of the bulk of the viscera.

#### MALE REPRODUCTIVE SYSTEM.

The males are usually smaller than the females and in the Strongylidæ may be readily distinguished from the latter by the presence of a copulatory bursa at the posterior end of the body, a membranous structure supported by rays or ribs, and serving as a clasping organ. The testicle, seminal vesicle, and vas deferens form a single continuous tubular thread-like structure, very tenuous and frequently much coiled and twisted in its proximal portion, and thicker and straighter in its distal portion, joining the intestine to form a cloaca which opens to the exterior through the anus.

The intromittent organs, or spicules, and the bursa present characters of great importance from the standpoint of classification.

### SPICULES.

The males of all the species of nematodes known to occur in the alimentary tract of ruminants with the exception of *Trichinella spiralis*, which is without spicules, possess spicules located in the posterior portion of the body. The spicules are composed of chitin, and by means of muscles with which they are supplied may be exserted through the anal opening. The Trichurinæ have but one spicule (*sp.*, figs. 139, 148) which is surrounded by a prepuce-like sheath (*sh.*, figs. 139, 148) that is evaginated when the spicule is exserted. This sheath in the genus *Trichuris* is armed with numerous spines. In the genus *Capillaria* it is unarmed in species occurring in ruminants. Two spicules are present in all the species parasitic in the alimentary canal of ruminants belonging to families other than the Trichinellidæ. In the Filariidæ one of the spicules is short and thick, the other long and filiform (fig. 129). The spicules in the Ascaridæ and Strongylidæ are equal or subequal in length. In the latter family, to which the bulk of the species of nematodes parasitic in ruminants belong, the spicules in several genera are relatively long and filiform (*sp.*, figs. 8, 90), in others short and more or less complicated and irregular in shape, but always elongated (*sp.*, figs. 39, 79). The long filiform spicules are usually alate; that is, supplied with one or two narrow longitudinal membranous lamellæ.

In the genus *Nematodirus* the two spicules are united, at least in their distal portion, by a membrane (*sp.*, fig. 89). Many species have in addition to the spicules a third chitinous piece, smaller than the spicules, situated just dorsal of them, usually not exsertile, and known as an accessory piece, or gubernaculum (*gub.*, figs. 115, 116). Spicules of the short type in certain species are divided distally into two or three processes; in some instances these processes form a pincer-like apparatus (fig. 63)

### BURSA.

A more or less well-developed bursa (figs. 4, 25) is present in the males of all species of Strongylidæ. A small bursa-like structure is present in the genus *Capillaria* (*b. m.*, figs. 148, 151), supported on each side by a short leg-like process. In the Filariidæ there are lateral membranes along the sides of the posterior end of the body of the male supported by several pairs of stalked papillæ (fig. 124). The Ascaridæ have papillæ on the tail of the male, but no lateral membranes. In both these families the anus is some distance from the tip of the tail. The males of the genus *Trichuris* (fig. 139) are without a bursa, and the anus is terminal.

The bursa in the Strongylidæ consists of three lobes, two lateral and one dorsal, supported by five systems of rays, a right and left ventral system, a right and left lateral system, and a dorsal system. The dorsal lobe may be shorter or longer than, or equal in length to, the lateral lobes. In the genus *Hæmonchus* it is not median in position but attached asymmetrically to one of the lateral lobes (fig. 35). A small accessory bursal membrane attached to the posterior end of the body ventral of the dorsal lobe is present in the genus *Ostertagia* (*a. b.*, figs. 45, 56). The dorsal lobe in the genus *Nematodirus* (figs. 89, 90) is very short and divided into two small lobules, located one on either side of the median line.

Each ventral system of rays[a] consists of two rays, designated as ventro-ventral (*v. v.*, fig. 25) and latero-ventral (*l. v.*, fig. 25). Each lateral system is divided into three rays, designated as externo-lateral (*e. l.*, fig. 25), medio-lateral (*m. l.*, fig. 25), and postero-lateral (*p. l.*, fig. 25). The ventral and lateral rays support the lateral lobes of the bursa. Each lateral lobe contains also a ray belonging to the dorsal system, known as the externo-dorsal ray (*e. d.*, fig. 25).

The dorsal system in addition to the paired externo-dorsal ray consists of a median dorsal ray (*d.*, fig. 25) which supports the dorsal lobe. This ray may extend nearly the entire length of the dorsal lobe unbranched (fig. 10), terminating in a digitate tip, or may divide into two main branches, each of which may give off subbranches on its inner or outer side (*t. d.*, fig. 45) or terminate in a digitate tip (*t. d.*, fig. 66). The externo-dorsal ray, already mentioned, in some species comes off from the stem of the dorsal ray (*e. d.*, fig. 25), in others originates at its base (*e. d.*, fig. 113). In *Nematodirus* the unpaired median ray is lacking, but is represented by two dorsal rays (*d.*, figs. 89, 90), each supporting one of the lobules of the dorsal lobe. In *Hæmonchus* the dorsal ray is entirely displaced to one side of the median line (*d.*, fig. 35). In *Monodontus trigonocephalus* and *M. phlebotomus* (figs. 3, 8) the dorsal ray (*d.*) extends backward on one side of the median line, dividing distally into three branches, one corresponding to the externo-dorsal ray (*e. d. l.*) and two (*t. d.*) corresponding to the usually symmetrical main branches of the dorsal ray. The other externo-dorsal ray (*e. d. r.*) in these two species takes its origin at or near the root of the dorsal ray.

The tips of the ventral, lateral, and externo-dorsal rays form small papillæ on the outer or inner surface of the bursa, those of the externo-dorsal and externo-lateral rays on the outer surface, the others on the inner surface.

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[a] Different authors have applied different names to the various rays supporting the bursa. In the present paper the plan proposed by Looss (1905o) is followed.

A pair of prebursal papillæ (*p. b. p.*, fig. 20) projecting from the lateral lines of the body and situated just in front of the base of the bursa is commonly present in the Strongylidæ.

The bursa is of special importance in the identification of species, because as a rule the details of its structure may be readily made out. In some species the bursa may be easily spread out flat; in others it is very difficult to prepare specimens, especially preserved specimens, so that the bursal characters can be determined. In many instances, however, when the bursa can not be spread out easily, a side view may be obtained from which sufficient may be seen to make possible the identification of the species.

### FEMALE REPRODUCTIVE SYSTEM.

The females may be distinguished from the males of the same species by their usually somewhat larger size, by the presence of eggs, and the possession of a vulva on the ventral surface of the body somewhere between the mouth and the anus, its position varying in different species. As in the male, the reproductive glands and ducts form tubular thread-like structures. In all of the nematodes occurring in the alimentary tract of ruminants, except the Trichinellidæ, there are two ovaries and two uteri. The uteri unite to form a single vagina, which opens through the vulva.

### VULVA.

Different species, genera, and families differ with respect to the location and shape of the vulva. In the Trichinellidæ (*, figs. 138, 147, 150) it is situated just back of the posterior end of the esophagus at the juncture of the slender anterior portion of the body and the thicker posterior portion. The vulva in the Strongylidæ (*, figs. 1, 11, 33) is usually behind the middle of the body, in some genera close to the anus. Its shape varies, but it is commonly elongated, usually transversely, sometimes longitudinally, and occasionally it is elongated in a diagonal direction. It is sometimes situated on a protuberance (*vul.*, fig. 27). Its lips may be salient, often vesicular. In some cases the vulva is covered by a more or less conspicuous backward projecting process (*lab.*, figs. 36, 42), which may be small and thin, or large, thick, and very prominent, as in *Hæmonchus*.

### VAGINA.

In the Trichinellidæ the exact point at which the uterus ends and the vagina begins is not readily determined, but in the other families the vagina is readily identified as that portion of the genital system extending from the juncture of the two uteri to the vulva. In many cases it is very short and practically nil (*vag.*, fig. 22), but in some species in which the males have long spicules it is correspondingly developed to a considerable length (*vag.*, fig. 32).

### UTERUS AND OVARY.

As already noted, in all forms parasitic in the alimentary tract of ruminants except the Trichinellidæ, there are two uteri and two ovaries. The terminal portions of the uteri in the Strongylidæ are modified at their juncture to form structures known as ovijectors (*ovij.*, fig. 42). Commonly three portions may be recognized in each ovijector, first, a cylindrical muscular portion fused end to end with the corresponding portion of the other ovijector (*ovij.* 1); second, a short bulbous sphincter-like muscular portion (*ovij.* 2), and third, a narrower cylindrical nonmuscular portion (*ovij.* 3) which joins the end of the uterus proper (*ut.*).

The ovaries are usually very long, narrower than the uteri, much coiled and twisted, and portions of them may be wound spirally about the intestine (*ov.*, fig. 132).

### EGGS.

The eggs (*e.*, figs. 27, 136) of all the nematodes parasitic in the alimentary tract of ruminants are oval or ellipsoidal in shape, and except in the Trichurinæ the shells are imperforate. In this subfamily (figs. 140, 149) there is a perforation at each pole of the egg closed by a plug-like operculum, and outside the chitinous shell there is a thin albuminous layer, smooth or with little projections. This outer albuminous layer is more conspicuous in the Ascaridæ; the thick-shelled eggs with an outer albuminous layer whose surface is roughened by numerous mammillate projections are very characteristic of the genus *Ascaris.*

In the Filariidæ, Strongylidæ, and Angiostomidæ the eggs usually have very thin shells, their size (length) ranging from 40$\mu$ in *Strongyloides* to 260$\mu$ in *Nematodirus.* Most species have eggs whose diameter is less than 100$\mu$. In *Gongylonema* the egg may contain a vermiform embryo when deposited, but in most genera the eggs when laid are in earlier stages of segmentation. The eggs of *Strongyloides* by the time they reach the outside world in the feces of the host frequently contain vermiform embryos, but the eggs of most species pass out of the body of the host before the embryos have developed beyond the so-called morula stage. An unusual condition relative to the eggs is met with in *Strongyloides ovocinctus.* Here the eggs after deposition, instead of occurring isolated among the intestinal contents of the host, are arranged in strings (fig. 137). Each string seems to be composed of the cast-off cuticle of an adult worm, packed with eggs. The adult worm apparently undergoes successive molts and the eggs (*e.*, fig. 136) as they pass out of the vulva lodge beneath the loosened outer cuticle, in which they remain when the worm abandons it.

## DESCRIPTION OF NEMATODES PARASITIC IN THE ALIMENTARY TRACT OF RUMINANTS.

According to the system of classification followed in the present paper, any species of nematode known to occur in the alimentary tract of ruminants may be placed in one of five families. The family to which any given specimen belongs may be determined by comparison with the following key:

### KEY TO FAMILIES OF NEMATODA.

1. Body at its middle more than 2 mm. in thickness ............... Ascaridæ, p. 24
   Body at its middle less than 2 mm. in thickness ................................ 2
2. Males lacking; parthenogenetic females with few eggs in uterus (not over 25); small slender forms not over 6 mm. long .................. Angiostomidæ, p. 104
   Diœcious, both males and females being distinguishable; females usually with numerous eggs in uterus .................................................. 3
3. Male with a single spicule, or without spicules; female with a single uterus and ovary; eggs, in oviparous species, with an opening at each pole closed by a plug-like operculum .................................... Trichinellidæ, p. 110
   Male with two spicules; female with double uterus and two ovaries; eggs without polar openings in the shell ................................................ 4
4. Male with unequal spicules, one short, and one much longer.... Filariidæ, p. 99
   Male with equal or subequal spicules ...................... Strongylidæ, p. 26

## FAMILY ASCARIDÆ COBBOLD, 1864.

FAMILY DIAGNOSIS.—Nematoda: Mouth usually surrounded with three lips which are often supplied with papillæ. One lip median, dorsal, the other two submedian, ventral, touching one another in the ventral median line. Males provided with two spicules. Females with a double ovary, oviparous. Development, so far as known, direct, without intermediate host.

TYPE GENUS.—*Ascaris* Linnæus, 1758.

### KEY TO GENERA OF ASCARIDÆ.

One genus in ruminants ......................................... ***Ascaris***, p. 24

### Genus ASCARIS Linnæus, 1758.

1758: *Ascaris* Linnæus, 1758a, pp. 644, 648.
1780: *Stomachida* Pereboom, 1780a, pp. 1-24.
1800: *Fusaria* Zeder, 1800a, pp. 6, 16-68.
1821: *Lombricoides* Mérat, 1821a, p. 225.

GENERIC DIAGNOSIS.—Ascaridæ (p. 24): Mouth with three well-developed lips, which generally have denticulated borders. Male with two equal spicules, and with numerous papillæ on the ventral surface of the body in front of and behind the anus. Vulva of female near or in front of the middle of the body. Shell of egg thick, with surface of outer albuminous layer raised in numerous mammillate projections.

TYPE SPECIES.—*Ascaris lumbricoides* Linnæus, 1758.

Two species of *Ascaris* are recognized as parasites of ruminants. These may be distinguished by the following key:

### KEY TO SPECIES OF ASCARIS.

Parasitic in sheep; male 7 to 15 cm. long, female 8 to 15 cm. long..*Ascaris ovis*, p. 25
Parasitic in cattle; male 15 to 25 cm. long, female 22 to 30 cm. long.
*Ascaris vitulorum*, p. 25

### **Ascaris ovis** Rudolphi, 1819.

1819: *Ascaris ovis* Rudolphi, 1819a, p. 54 (from intestine, *Ovis domestica* [=*O. aries*]).

Specific diagnosis.—*Ascaris* (p. 24): *Male* 7 to 15 cm. long by 2 mm. in maximum thickness. Ventral surface of tail with two rows of 45 to 50 papillæ each. Three pairs of these papillæ are postanal, and there is one unpaired papilla near the extremity of the tail.

*Female* 8 to 15 cm. long, thicker than the male. Vulva toward the anterior third of the body.

Host.—*Sheep (*Ovis aries*).

Location.—Small intestine.

Localities collected.—Europe, United States.

This species is of rather rare occurrence. It has been seen a number of times in Europe. Curtice (1890c, p. 151) reports the finding of an *Ascaris* in sheep, which he identifies as *Ascaris lumbricoides*. The Bureau of Animal Industry collection contains specimens of *Ascaris* collected from sheep at Blairsville, Pa., at Brookings, S. Dak., and at Bethesda, Md.

It is considered questionable by some authors whether *Ascaris ovis* represents a distinct species, or whether it is simply *Ascaris lumbricoides* (man) or *Ascaris suum* (pig) in an unusual host.

### **Ascaris vitulorum** Goeze, 1782.

1782: *Ascaris vitulorum* Goeze, 1782a, p. 72 (from *Bos taurus*, Europe).
1790: *Ascaris vituli* Gmelin, 1790a, p. 3032 (in part).

Specific diagnosis.—*Ascaris* (p. 24): Lips without papillæ, narrowed anteriorly. Tail terminated by a mucronate conical tip. Esophagus followed by a rudimentary ventricle.

*Male* 15 to 25 cm. long by 3 mm. in maximum thickness. Ventral surface of tail supplied with two irregular rows of 10 to 15 papillæ each, all preanal.

*Female* 22 to 30 cm. long by 5 mm. in thickness. Vulva toward the anterior sixth of the body. Eggs 75 to 80 μ in length.

Hosts.—*Cattle (*Bos taurus*); zebu (*Bos indicus*).

Location.—Small intestine, occasionally fourth stomach.

Localities collected.—Europe, Japan, Ceylon, West Indies.

This parasite seems to be more common in calves than in adults. The Bureau of Animal Industry collection contains specimens collected in Antigua and in Cuba. Schneider (1866a, p. 36) reports an *Ascaris* from a cow which may possibly belong to the species *A. vitulorum*. Schneider, however, identifies it as *Ascaris megalocephala* (=*A. equorum*), a species of common occurrence in the horse. Neumann (1892a, p. 404) states that ascarids in cattle may cause local inflammation of the intestinal mucosa, and colic, and exceptionally may cause a rupture of the intestine when present in large numbers.

## FAMILY STRONGYLIDÆ COBBOLD, 1864.

FAMILY DIAGNOSIS.—Nematoda: Head with six more or less distinct circumoral papillæ. Buccal capsule present or absent, may be armed with teeth in its interior. Esophagus without posterior bulb. Males with two equal or subequal spicules, and with a more or less well developed caudal bursa, each lateral lobe of which is usually supplied with six supporting rays. Females with two ovaries; vulva may be in front of the middle of the body, but is usually behind the middle. Oviparous. Development, so far as known, direct, without intermediate host.

TYPE GENUS.—*Strongylus* Mueller, 1780.

Two subfamilies may be distinguished in this family.

### KEY TO SUBFAMILIES OF STRONGYLIDÆ.

Mouth cavity enlarged to form a buccal capsule; diameter of head over 75 μ. Strongylinæ, p. 26

Mouth cavity very small, not enlarged to form a buccal capsule; diameter of head less than 75 μ .......... Metastrongylinæ, p. 47

## Subfamily STRONGYLINÆ Railliet, 1893.

SUBFAMILY DIAGNOSIS.—Strongylidæ (p. 26): Mouth cavity enlarged to form a buccal capsule which may or may not be provided with teeth in its interior.

TYPE GENUS.—*Strongylus* Mueller, 1780.

Five[a] genera belonging to the subfamily Strongylinæ are represented among the nematodes parasitic in the alimentary tract of ruminants.

### KEY TO GENERA OF STRONGYLINÆ.

1. Buccal capsule armed with strong, recurved chitinous teeth at its entrance. *Agriostomum*, p. 27

Buccal capsule without teeth at its entrance, may be supplied with teeth or lancets at its base .......... 2

2. Buccal capsule small (less than three-fourths the diameter of the head); its chitinous framework supplied on its inner surface with one or two crowns of delicate chitinous leaf-like processes which project forward and inward; cuticle surrounding the mouth usually inflated to form an annular mouth collar, sharply limited behind by a deep constriction .......... 4

Buccal capsule large (more than three-fourths the diameter of the head); mouth opening not surrounded by a vesicular mouth collar .......... 3

3. Buccal capsule very large, without teeth or lancets in its interior; border of mouth armed with a double crown of numerous small triangular processes or denticles .......... *Chabertia*, p. 35

Buccal capsule supplied at its base with a strong dorsal tooth projecting forward into its cavity, and with 2 or 4 ventral teeth or lancets.... *Monodontus*, p. 27

4. Buccal capsule longer than broad; medio-lateral and postero-lateral rays of male bursa divergent .......... *Eucyathostomum*, p. 38

Buccal capsule broader than long; medio-lateral and postero-lateral rays of male bursa close together, parallel .......... *Œsophagostomum*, p. 40

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[a] Including *Gaigeria* there are six genera. See Addendum, p. 124.

### Genus AGRIOSTOMUM Railliet, 1902.

1902: *Agriostomum* Railliet, 1902b, pp. 107–108, 110.

Generic diagnosis.—Strongylinæ (p. 26): Buccal capsule rather deep, communicating with the esophagus by a wide opening at its base. Buccal capsule without teeth or lancets at its base, but surrounded at its entrance by a chitinous ring armed with strong, recurved, hook-like teeth. Cephalic extremity bent dorsally, supplied anteriorly with a projecting cuticular plate, which apparently forms the boundary of the mouth.

Type species.—*Agriostomum vryburgi* Railliet, 1902.

#### KEY TO SPECIES OF AGRIOSTOMUM.

One species ........................................ *Agriostomum vryburgi*, p. 27

### **Agriostomum vryburgi** Railliet, 1902.

1902: *Agriostomum vryburgi* Railliet, 1902b, pp. 107–108 (from duodenum, *Bibos indicus* [=*Bos indicus*], Sumatra).

Specific diagnosis.—*Agriostomum* (p. 27): Body cylindroidal, whitish in color, slightly attenuated at the ends. Striation of the cuticle very delicate, scarcely perceptible. Two delicate cervical papillæ at the level of the nerve ring, each consisting of a short, bluntly pointed process upon a cylindrical stalk. Cephalic extremity slightly inflated at the level of the buccal capsule. Buccal capsule ovoid, with chitinous ring at its anterior border armed with 8 strong recurved, hook-like teeth, symmetrically placed on each side; the two first (ventral) very close together, the two last (dorsal) with points facing one another, and with a rather large interval between their bases. The third on each side is apparently the most developed, the fourth or dorsal the least developed. Although the cuticle is not inflated in the cervical region to form a vesicular swelling, yet at some distance behind the buccal capsule there is present a ventral groove similar to that found in the œsophagostomes.

*Male* 9.2 mm. long, 300 μ thick. Bursa short, rather narrow, lobed. Spicules equal, slightly swollen at their base, alate and transversely striated, 840 μ long.

*Female* 14.5 to 15.5 mm. long, 450 μ thick near the middle. Tail very short, thick, blunt; anus 150 μ from its tip, upon a slight protuberance; vulva 470 μ from its tip, upon a more prominent protuberance. Eggs ellipsoidal or subcylindrical, 170 to 195 μ long by 60 to 92 μ wide, in process of segmentation when deposited.

Host.—Zebu (*Bos indicus*).

Location.—Duodenum.

Locality collected.—Sumatra.

This species has been collected by Dr. Vrijburg, veterinarian at Deli, Sumatra, and described by Railliet (1902b) from whom the above description and the diagnosis of the genus of which it is the type are taken.

### Genus MONODONTUS[a] Molin, 1861.

1861: *Monodontus* Molin, 1861a, pp. 435, 463–470.

1902: *Bunostomum* Railliet, 1902b, pp. 108–109, 110 (type species, *Bunostomum trigonocephalum* [Rudolphi, 1808]).

Generic diagnosis.—Strongylinæ (p. 26): Cuticle transversely striated. Buccal capsule supplied at its base with a strong dorsal tooth projecting forward into its cavity, and with two or four ventral lancets; and supplied ventrally at its entrance with two highly refractile chitinous pieces, continuing as two thin plates with rounded edges, almost contiguous at their inner border, and joining along their outer border with two dorsal plates, likewise thin with rounded edges, in such a manner that the outline of these structures forms a sinuous and continuous line. Six circumoral papillæ; two lateral, each with a slender prolongation upon the dorsal plates, and four submedian, the dorsal submedian papillæ shorter than the ventral. Cephalic extremity curved dorsally. Cervical papillæ short and obtuse.

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[a] See Addendum, p. 124.

TYPE SPECIES.—*Monodontus semicircularis* Molin, 1861.

Three species of *Monodontus* are recognized among the nematodes of ruminants. With regard to one of these, *Monodontus longecirratus*, it is questionable whether it properly belongs in this genus in view of the fact that the dorsal ray in this species is unbranched, whereas in *Monodontus semicircularis* (the type of the genus), as described and figured by Molin (1861a), the dorsal ray divides into two prominent branches. Until, however, more is known relative to the details of structure in the type-species of *Monodontus* and in *M. longecirratus* it is considered advisable to retain the latter in the genus *Monodontus*.

Railliet has proposed the name *Bunostomum* to replace *Monodontus* on account of the existence of very similar early generic names, *Monodon* Linnæus, *Monodonta* Lamarck, and *Monodontes* Montf. Under the International Code of Zoological Nomenclature *Monodontus* Molin is not invalidated by any of these three names in spite of their great similarity in spelling. *Bunostomum* may be recognized if it can be shown that *Monodontus semicircularis* and *M. trigonocephalus* are sufficiently different to warrant placing them in separate genera, but at present our knowledge of the former species is too incomplete to justify the separation.

### KEY TO SPECIES OF MONODONTUS.

1. Dorsal ray of bursa of male median with tridigitate tip; externo-dorsal ray originates at the base of the dorsal ray; male 18 mm. long, female 23 mm. long.
*Monodontus longecirratus*, p. 34

Dorsal ray of bursa asymmetrically situated on the left-hand side of the median line; right externo-dorsal ray originates from the stem of the dorsal ray at or near its base; distally the dorsal ray divides into 3 branches, namely, the right externo-dorsal ray, and two terminal branches with tridigitate tips..........2

2. Dorsal buccal tooth long; length of its dorsal border greater than the distance from its tip to the opening of the mouth; 2 ventral buccal teeth; spicules of male 600 to 640μ long; male 12 to 17 mm. long, female 19 to 26 mm. long.
*Monodontus trigonocephalus*, p. 28

Dorsal buccal tooth short; length of its dorsal border less than the distance from its tip to the opening of the mouth; 2 ventral buccal teeth, and 2 subventral buccal teeth or lancets; spicules of male 3.5 to 4 mm. long; male 10 to 12 mm. long, female 16 to 19 mm. long................ *Monodontus phlebotomus*, p. 31

### **Monodontus trigonocephalus**[a] (Rudolphi, 1808) Railliet, 1900.

(Figs. 1–5.)

1808: *Strongylus trigonocephalus* Rudolphi, 1808a, pl. 2, figs. 5–6; 1809a, pp. 231–232 (based on specimens said to have been collected from the stomach of a dog).[b]

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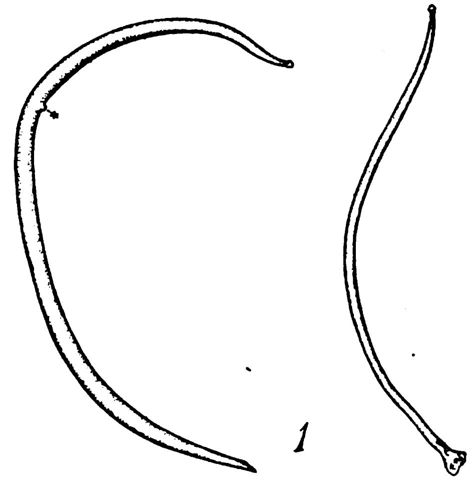
[a] See Addendum, p. 124.

[b] Apparently the specimens were improperly labelled, as Railliet has pointed out, or perhaps the dog from which the specimens were collected had just eaten the intestines of an infested sheep.



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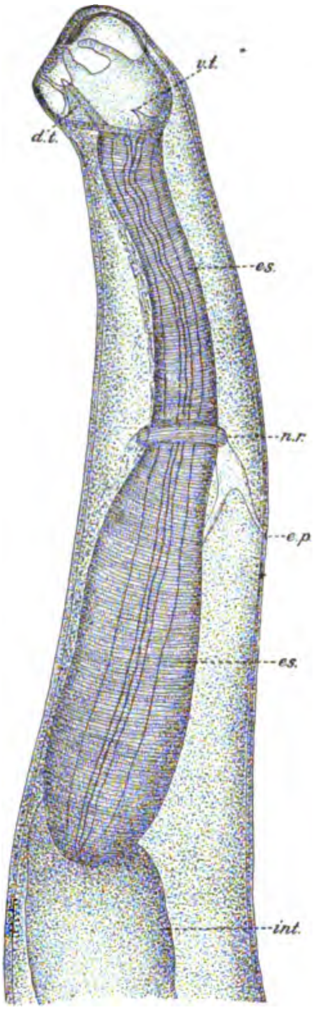

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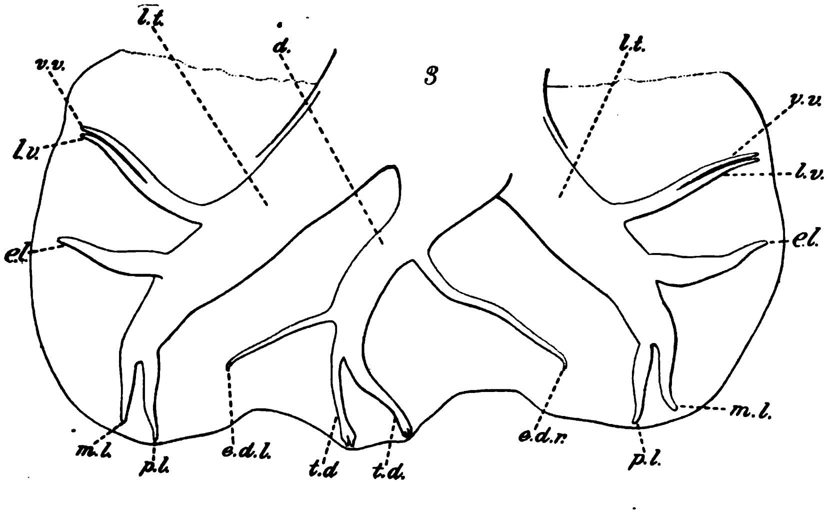
FIG. 1.—*Monodontus trigonocephalus.* Male at right, female at left. * Vulva. × 5. (Original.)

FIG. 2.—*Monodontus trigonocephalus.* Anterior end of body viewed from right side. *d. t.*, dorsal buccal tooth; *e. p.*, excretory pore; *es.*, esophagus; *int.*, intestine; *n. r.*, nerve ring; *v. t.*, ventral buccal tooth. × 75. (Original.)

FIG. 3.—*Monodontus trigonocephalus.* Bursa of male spread out. Dorsal view. *d.*, dorsal ray; *e. d. l.*, left externo-dorsal ray; *e. d. r.*, right externo-dorsal ray; *e. l.*, externo-lateral ray; *l. t.*, trunk of rays of lateral lobe; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *t. d.*, terminal branch of dorsal ray; *v. v.*, ventro-ventral ray. × 75. (Original.)



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1829: *Strongylus cernuus* Creplin, 1829b, pp. 9–10 (from *Ovis aries*).
1845: *Sclerostoma hypostomum* (Rudolphi) Dujardin, 1845a, pp. 255–257 (in part).
1851: *Dochmius hypostomus* (Rudolphi) Diesing, 1851a, p. 301 (in part).
1861: *Monodontus wedlii* Molin, 1861a, pp. 467–469.
1868: *Dochmius cernuus* (Creplin) Baillet, 1868a, pp. 547–557.
1885: *Uncinaria cernua* (Creplin) Railliet, 1885a, p. 362, fig. 254.
1900: *Strongylus* (*Monodontus*) *cernuus* (Creplin) Railliet, 1900d, p. 86.
1900: *Uncinaria* (*Monodontus*) *cernua* (Creplin) Railliet, 1900d, p. 87.
1900: *Monodontus trigonocephalus* (Rudolphi) Railliet, 1900d, p. 87.
1902: *Bunostomum trigonocephalum* (Rudolphi) Railliet, 1902b, p. 108.

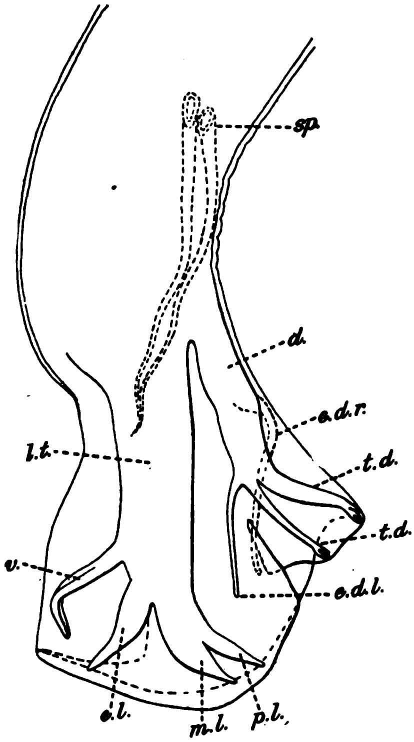

FIG. 4.—*Monodontus trigonocephalus.* Bursa of male viewed from left side. *d.*, dorsal ray; *e. d. l.*, left externo-dorsal ray; *e. d. r.*, right externo-dorsal ray; *e. l.*, externo-lateral ray; *l. t.*, trunk of rays of lateral lobe; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *sp.*, spicules; *t. d.*, terminal branch of dorsal ray; *v.*, ventral rays. × 75. (Original.)

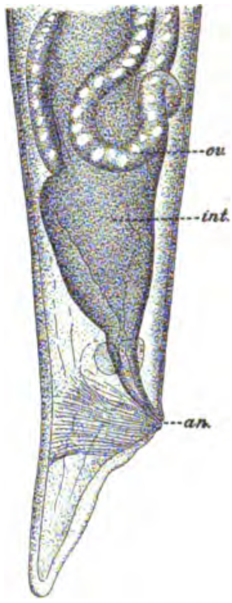

FIG. 5.—*Monodontus trigonocephalus.* Posterior end of body of female viewed from right side. *an.*, anus; *int.*, intestine; *ov.*, ovary. × 75. (Original.)

SPECIFIC DIAGNOSIS.—*Monodontus* (p. 27): Diameter of head (dorso-ventral) 150 to 200$\mu$. Dorsal buccal tooth long (*d. t.*, fig. 2); length of its dorsal border greater than the distance from its tip to the opening of the mouth. Two short ventral buccal teeth or lancets (*v. t.*, fig. 2); distance from the base of the buccal capsule to the tips of these teeth much less than the distance to the tip of the dorsal tooth. Esophagus (*es.*, fig. 2) 0.8 to 1.25 mm. in length. Cervical papillæ slightly in front of the middle of the esophagus.

*Male* 12 to 17 mm. long, slightly less than 0.5 mm. in thickness. Bursa (figs. 3, 4) funnel shaped; dorsal median lobe somewhat shorter than the lateral lobes. Ventral and lateral rays come off from a large common trunk (*l. t.*, figs. 3, 4), that of the left side larger than that of the right. The two ventral rays (*v. v.*, *l. v.*, fig. 3; *v.*, fig. 4) are long and slender, separated by a narrow cleft except in their proximal portion where they are united, taking origin from the ventral side of the common trunk at a point more than half way from its root to the origin of the externo-lateral ray. The externo-lateral ray (*e. l.*, figs. 3, 4) diverges widely from the other two lateral rays, and is curved ventrally, while the latter are curved dorsally. The postero-lateral (*p. l.*, figs. 3, 4) and medio-lateral rays (*m. l.*, figs. 3, 4) diverge somewhat from one another, and the former is a little longer than the latter, so that its tip lies nearer the border of the bursa. Distance between the tips of the medio-lateral and externo-lateral rays slightly greater than that between the latter and the tips of the ventral rays. Dorsal ray (*d.*, figs. 3, 4) asymmetrically branched. A long slender externo-dorsal ray (*e. d. r.*, figs. 3, 4) comes off from the stem of the dorsal ray near its root, on the right side. The stem of the dorsal ray extends backward on the left-hand side of the median line and a little more than half way between its root and the posterior border of the median dorsal lobe of the bursa, forks into three branches, namely, the left externo-dorsal ray (*e. d. l.*, figs. 3, 4), and two branches (*t. d.*, figs. 3, 4) which terminate at the posterior border of the dorsal median lobe of the bursa, each in three usually unequal digitations. Spicules (*sp.*, fig. 4) 600 to 640μ long by about 30μ in diameter near their proximal end, gradually attenuated to a sharp point posteriorly, slightly twisted, alate.

*Female* 19 to 26 mm. long by 0.5 to 0.75 mm. in maximum thickness. Posterior end of body (fig. 5) gradually attenuated, tail thick, short, with blunt, rounded tip. Anus (*an.*, fig. 5) 250 to 275μ from tip of tail. Vulva elliptical, transversely elongated, with narrow lips, usually not salient, situated a little more than one-third the length of the body from the anterior end. Vagina short, less than 200μ in length, may be bent S-like. Combined length of the muscular portions of the two ovijectors at least 450μ. Eggs ellipsoidal, 75 to 83μ long by 38 to 45μ wide, in course of segmentation when deposited.

HOSTS.—*Sheep (*Ovis aries*); *goat (*Capra hircus*); chamois (*Rupicapra rupicapra*).

LOCATION.—Small intestine.

LOCALITIES COLLECTED.—Europe, United States.

*Monodontus trigonocephalus* is a frequent parasite of sheep in the southern United States and has been found as far north as New York. It is common among sheep in the neighborhood of Washington, D. C. It is a blood sucker, and when numerous is no doubt responsible for considerable injury to its host.

Its life history is presumably similar to that of the hookworm of man; that is, it undergoes a direct development without intermediate host.

### **Monodontus phlebotomus**[a] Railliet, 1900.

(Figs. 6-9.)

1803: *Strongylus radiatus* Rudolphi, 1803a, pp. 13–15 (in part).

1866: *Strongylus radiatus* Rudolphi of Schneider, 1866a, pp. 128, 132, 137, 139, 141, 144.

1868: *Dochmius radiatus* (Rudolphi) Leuckart, 1868a, p. 411.

1885: *Uncinaria radiata* (Rudolphi) Railliet, 1885a, pp. 362–363.

1900: *Monodontus* sp. Railliet, 1900e, p. 106.

1900: *Monodontus phlebotomus* Raillíet, 1900b, p. 781.

1902: *Bunostomum phlebotomum* Railliet, 1902b, pp. 108–109 (*Strongylus radiatus* Rudolphi of Schneider, 1866, renamed).

1906: *Bunostomum radiatum* (Schneider) Linstow, 1906, Centralbl. f. Bakteriol., Parasitenk. [etc.], Jena, 1 Abt., v. 43 (1), 22. Dec., Originale, pp. 91–92, figs. 6, 8.

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[a] See Addendum, p. 124.

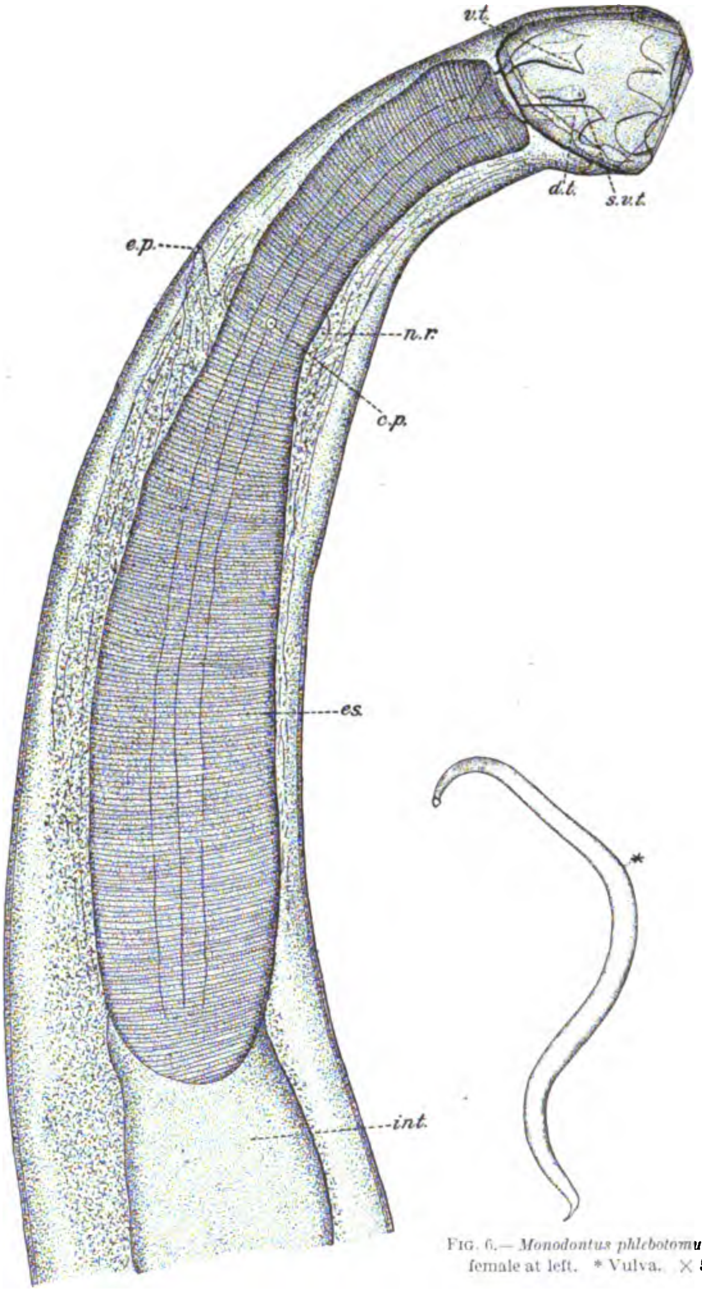

FIG. 7.—*Monodontus phlebotomus.* Anterior end of body viewed from left side. *c. p.*, cervical papilla; *d. t.*, dorsal buccal tooth; *e. p.*, excretory pore; *es.*, esophagus; *int.*, intestine; *n. r.*, nerve ring; *s. v. t.*, subventral buccal tooth; *v. t.*, ventral buccal tooth. × 75. (Original.)

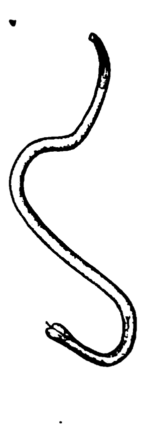

FIG. 6.—*Monodontus phlebotomus.* Male at right, female at left. * Vulva. × 5. (Original.)

Specific diagnosis.—*Monodontus* (p. 27): Diameter of head (dorso-ventral) 200 to 250μ. Dorsal buccal tooth (*d. t.*, fig. 7) short; length of its dorsal border less than the distance from its tip to the opening of the mouth. Two subventral buccal teeth (*s. v. t.*, fig. 7) or lancets in addition to two ventral teeth (*v. t.*, fig. 7). Tips of all the buccal teeth about equally distant from the base of the buccal capsule. Esophagus (*es.*, fig. 7) 1.25 to 1.5 mm. or slightly more in length. Cervical papillæ (*c. p.*, fig. 7) opposite the anterior portion of the middle third or the posterior portion of the anterior third of esophagus.

*Male* 10 to 12 mm. long, slightly less than 0.5 mm. in thickness. Bursa (fig. 8) funnel shaped; dorsal median lobe somewhat shorter than the lateral lobes. Ventral and lateral rays come off from a large common trunk (*l. t.*, fig. 8), that of one side of the bursa larger than that of the other. The two ventral rays (*v.*, fig. 8) are long and slender, separated by a narrow cleft except in their proximal portion where they are united, taking origin from the ventral side of the common trunk a little less than half way between its root and the origin of the externo-lateral ray. The externo-lateral ray (*e. l.*, fig. 8) diverges widely from the other two lateral rays which are close together and but slightly divergent distally. The externo-lateral ray curves ventrally, the other two dorsally. The postero-lateral ray (*p. l.*, fig. 8) is slightly longer than the medio-lateral ray (*m. l.*, fig. 8), its tip in consequence being nearer

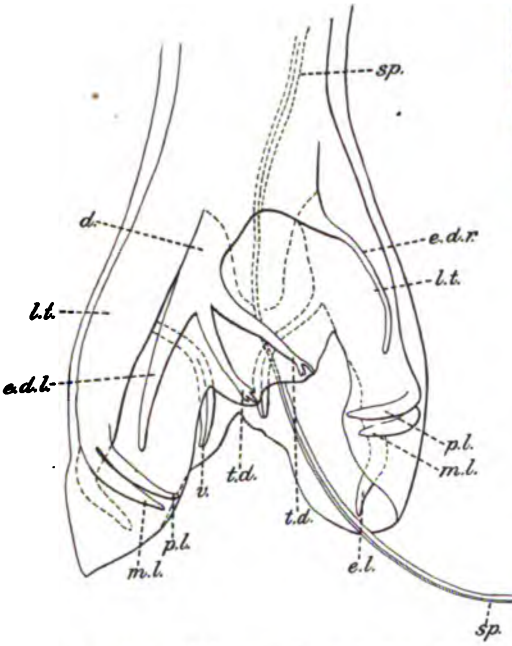

Fig. 8.—*Monodontus phlebotomus*. Bursa of male. Dorsal view. *d.*, dorsal ray; *e. d. l.*, left externo-dorsal ray; *e. d. r.*, right externo-dorsal ray; *e. l.*, externo-lateral ray; *l. t.*, trunk of rays of lateral lobe; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *sp.*, spicules; *t. d.*, terminal branch of dorsal ray; *v.*, ventral rays. × 75. (Original.)

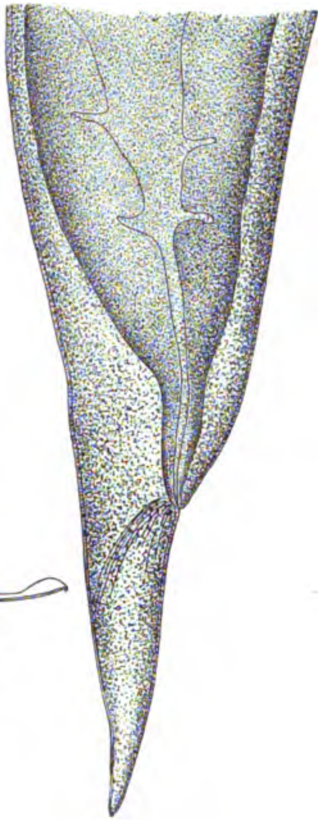

Fig. 9.—*Monodontus phlebotomus*. Posterior end of body of female viewed from right side. × 75. (Original.)

the border of the bursa. Distance between the tips of the medio-lateral and externo-lateral rays slightly greater than that between the latter and the tips of the ventral rays. Dorsal ray (*d.*, fig. 8) asymmetrically branched. A long slender externo-dorsal ray (*e. d. r.*, fig. 8) comes off at the root of the dorsal ray on its right side. The stem of the dorsal ray extends backward on the left-hand side of the median line and about half way between its root and the posterior edge of the median dorsal lobe of the bursa, forks into three branches, namely, the left externo-dorsal ray (*e. d. l.*, fig. 8), and two branches (*t. d.*, fig. 8) which terminate at the posterior edge of the median dorsal lobe of the bursa each in three usually unequal digitations. Spicules (*sp.*, fig. 8) 3.5 to 4 mm. long, filiform, alate.

*Female* 16 to 19 mm. in length by a little more than 0.5 mm. in thickness. Posterior end of body (fig. 9) gradually attenuated, then near anus suddenly reduced in size, and terminating in a rather slender bluntly-pointed tail. Anus 400 to 500$\mu$ from the tip of the tail. Vulva elliptical, transversely elongated, with narrow, salient lips, situated a little in front of the middle of the body. Vagina long and sinuous. Combined length of the muscular portions of the two ovijectors at least 1 mm. Eggs ellipsoidal, 75 to 98$\mu$ long by 40 to 50$\mu$ wide, in course of segmentation when deposited.

HOSTS.—*Cattle (*Bos taurus*); zebu (*Bos indicus*).

LOCATION.—Small intestine.

LOCALITIES COLLECTED.—United States, Cuba, Panama, Europe, Sumatra.

*Monodontus phlebotomus* has been found by Dawson (1906, Bull. 86, Florida Exper. Sta.) associated with and a probable cause of the so-called "salt sickness" of Florida, which is characterized "at first by low fever, diarrhea, loss of appetite, soon becoming chronic, with continuance of low fever, constipation, loss of appetite, progressive emaciation, and pronounced anemia, which in many cases terminates fatally." Treatment with thymol has been recommended for hookworm disease in cattle, but Conradi and Barnett (1908, Bull. 137, South Carolina Exper. Sta.) found that thymol in a dose of 150 grains had no apparent effect upon the parasites in one case in which this remedy was used.

The same authors (1908) have studied the development of the hookworm of cattle from the egg to the final larval stage. This portion of the life history is very similar to that of *Hæmonchus contortus*. Presumably infection of cattle occurs through swallowing the larvæ, or as a result of the entrance of larvæ through the skin in a similar manner to that occurring in the case of the hookworms of man and of the dog.

### **Monodontus longecirratus**[1] (Linstow, 1879) Ransom, 1911.

(Fig. 10.)

1879: *Strongylus longecirratus* Linstow, 1879b, pp. 332–333, pl. 5, fig. 18 (from intestine of *Bos grunniens* L.).

1909: *Bunostomum longecirratum* (Linstow, 1879) Railliet and Henry, 1909b, p. 170.

1911: *Monodontus longecirratus* (Linstow, 1879) Ransom, 1911, pp. 14, 28, 34–35, 121, fig. 10 (the present paper).

SPECIFIC DIAGNOSIS.—*Monodontus* (p. 27): Cuticle with very fine transverse striations. Esophagus very muscular, one-thirteenth of the length of the body. Buccal capsule large, armed with chitinous teeth at its base.

*Male* 18 mm. long by 0.4 mm. wide. Spicules unusually long and slender, measuring 4.5 mm. in length. Bursa (fig. 10) with 3 lobes. Lateral lobes large. Ventral rays (probably two in each lateral lobe, close together and parallel, though Linstow describes and figures the ventral rays as single) long, slender, with tips terminating some distance from the border of the bursa near the tip of the externo-lateral ray, which is curved in a ventral direction and reaches nearly to the border of the bursa. The medio-lateral and postero-lateral rays curve in a dorsal direction and their tips are much nearer to the tip of the externo-dorsal ray than to the tip of the externo-lateral ray. The externo-dorsal ray is long and slender. The ventral and lateral rays come off from a large common trunk. The externo-dorsal ray originates at the junction of this common trunk with the dorsal ray at the base of the bursa. The dorsal lobe of the bursa is much smaller than the lateral lobes, and is supported by the unpaired dorsal ray which terminates near the posterior border of the dorsal lobe in a tri-digitate tip.

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[1] See Addendum, p. 124.

*Female* 23 mm. long by 1 mm. in thickness, with a slender, rather long, pointed tail.

HOST.—Yak (*Bos grunniens*).

LOCATION.—Intestine.

LOCALITY COLLECTED.—(?)

Only one occurrence of this species has been recorded. The foregoing diagnosis is based on the description and figure given by Linstow (1879b).

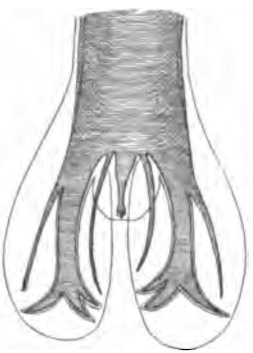

**FIG. 10.**—***Monodontus longecirratus*. Bursa of male. Enlarged. (After Linstow, 1879b, pl. 5, fig. 18).**

## Genus CHABERTIA Railliet & Henry, 1909.

1909: *Chabertia* Railliet and Henry, 1909b, p. 169.

GENERIC DIAGNOSIS.—Strongylinæ (p. 26): Anterior end of head obliquely truncate so that the mouth faces antero-ventrally. Buccal capsule large, without teeth in its interior. Border of mouth armed with a double crown of numerous small triangular pointed processes. Dorsal median lobe of bursa slightly longer than the lateral lobes. Latero-ventral and ventro-ventral rays close together. Medio-lateral and postero-lateral rays close together. Externo-lateral ray diverges somewhat the medio-lateral ray. Dorsal ray bifurcated toward its posterior end and each bifurcation divided into two terminal branches, the inner of which is the longer. Externo-dorsal rays originate from the dorsal ray between its root and its bifurcation. Prebursal papillæ present. Spicules long, tubular, slender. Gubernaculum, or accessory piece, present. Vulva of female a short distance in front of the anus

TYPE SPECIES.—*Chabertia ovina* (Fabricius, 1788) Railliet and Henry, 1909.

### KEY TO SPECIES OF CHABERTIA.

One species................................................*Chabertia ovina*, p. 35

### **Chabertia ovina** (Fabricius, 1788) Railliet and Henry, 1909.

(Figs. 11-14.)

1788: *Strongylus ovinus* Fabricius, 1788 (on the authority of Railliet, 1893a, p. 463).—Fabricius, 1794a, pp. 5-12, pl. 1, figs. 1a-1c, 2a-2d (from intestine of sheep, Europe).

1802: *Strongylus contortus* Rudolphi, 1802a, pp. 15-17 (in part).

1819: *Strongylus hypostomus* Rudolphi, 1819a, pp. 33, 263 (from cecum, *Antilope rupicupra* [=*Rupicapra rupicapra*], Europe).

1845: *Sclerostoma hypostomum* (Rudolphi) Dujardin, 1845a, pp. 255-257.

1851: *Dochmius hypostomus* (Rudolphi) Diesing, 1851a, p. 301.

1867: *Sclerostomum hypostomum* (Rudolphi) Leuckart, 1867b, p. 19.

1899: *Sclerostomum ovinum* Stossich, 1899d, pp. 102-103.

1909: *Chabertia ovina* (Fabricius) Railliet and Henry, 1909b, p. 169.

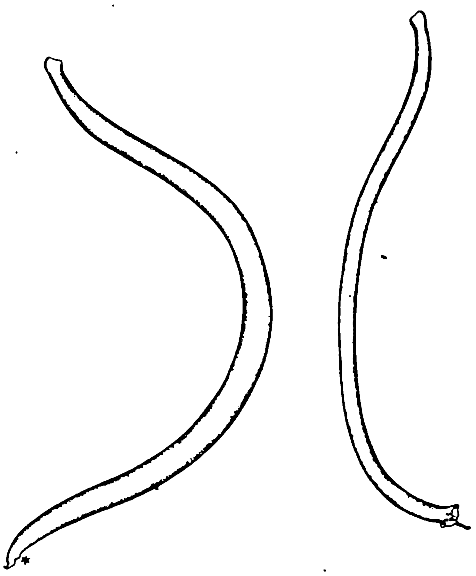

FIG. 11.—*Chabertia ovina.* Male at right, female at left. * Vulva. × 5. (Original.)

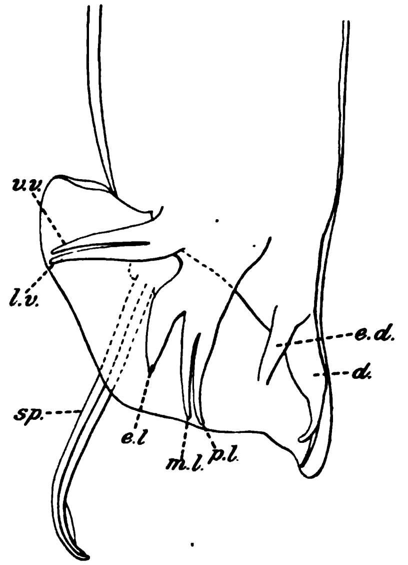

FIG. 13.—*Chabertia ovina.* Bursa of male viewed from left side. *d.*, dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *sp.*, spicules; *v. v.*, ventro-ventral ray. × 75. (Original.)

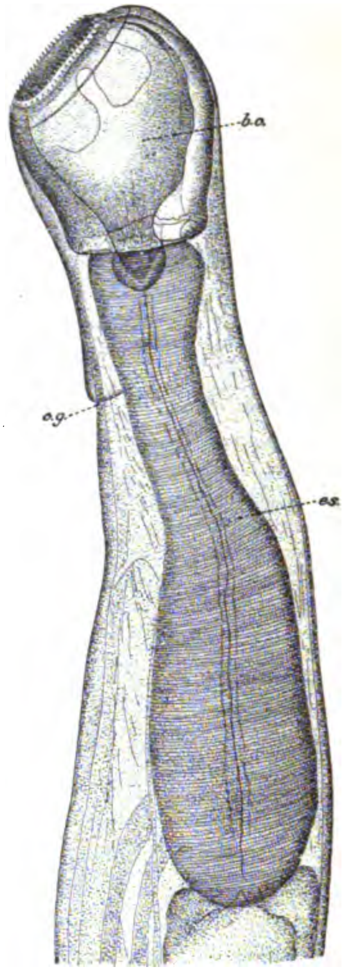

FIG. 12.—*Chabertia ovina.* Anterior end of body viewed from left side. *b. c.*, buccal capsule; *c. g.*, cervical groove; *es.*, esophagus. × 75. (Original.)

SPECIFIC DIAGNOSIS.—*Chabertia* (p. 35): Body cylindroidal, almost uniform in thickness. Diameter of head (fig. 12) slightly greater than that of the cervical region of the body and nearly equal to the maximum diameter of the body. Anterior end of head obliquely truncate, so that the mouth faces antero-ventrally. Border of mouth armed with a double crown of numerous small triangular pointed processes or denticles. Buccal capsule (*b. c.*, fig. 12) very large, without teeth in its interior. On the ventral surface of the body just in front of the excretory pore, which is about one-fourth of the length of the body from its anterior end, is a short transverse cervical groove (*c. g.*, fig. 12). Cuticle on ventral surface in front of this groove very slightly inflated. Esophagus (*es.*, fig. 12) claviform, 1.2 to 1.4 mm. long. Nerve ring about one-third the length of the esophagus from its anterior end. Cervical papillæ not evident.

*Male* 13 to 14 mm. long by a little over one-third mm. in thickness. Dorsal median lobe of bursa (fig. 13) slightly longer than the lateral lobes. Tips of ventral, medio-lateral, postero-lateral, and dorsal rays reach the border, or nearly to the border of the bursa. Tips of the externo-lateral and externo-dorsal rays fall considerably short of the border, the former slightly nearer the border of the bursa than the latter. Distance between the tips of these two rays slightly less than the distance between the tip of the externo-lateral, and the tip of the latero-ventral ray. Ventro-ventral (*v. v.*, fig. 13) and latero-ventral (*l. v.*, fig. 13) rays close together. Medio-lateral (*m. l.*, fig. 13) and postero-lateral (*p. l.*, fig. 13) rays closely approximated throughout their course. Externo-lateral ray (*e. l.*, fig. 13) diverges somewhat from the medio-lateral ray. Externo-lateral and externo-dorsal rays considerably thicker than the ventral, medio-lateral and postero-lateral rays, which are about equal in thickness. Externo-dorsal rays (*e. d.*, fig. 13) take origin from the stem of the dorsal ray about one-third the distance from its root to its bifurcation. Dorsal ray (*d.*, fig. 13) bifurcated at about three-fifths the distance from its root to the posterior border of the dorsal median lobe of the bursa. Each of the branches of the dorsal ray divided into two—namely, an inner branch, which reaches the edge of the bursa, and an outer branch, which is thicker than the inner branch and about half as long, not reaching the border of the bursa. Prebursal papillæ large. Spicules (*sp.*, fig. 13) 1.3 to 1.7 mm. long, tubular, slender, about 30$\mu$ in diameter anteriorly, tapering to an acute point posteriorly, alate. Gubernaculum 80 to 100$\mu$ long.

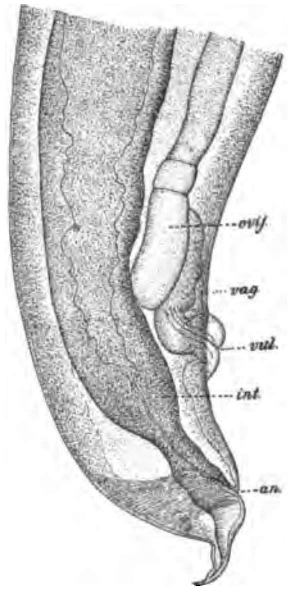

FIG. 14.—*Chabertia ovina*. Posterior end of body of female viewed from right side. *an.*, anus; *int.*, intestine; *ovij.*, ovijector; *vag.*, vagina; *vul.*, vulva. × 75. (Original.)

*Female* 17 to 20 mm. long by a little less than one-half mm. in maximum thickness. Posterior end of body (fig. 14) gradually attenuated from in front of the vulva toward the anus. Behind the anus the body is suddenly reduced in diameter, terminating in a sharply pointed short mucronate tail. The body curves ventrally behind the vulva, and dorsally behind the anus. Anus (*an.*, fig. 14) 200 to 230$\mu$ from the tip of the tail. Vulva (*vul.*, fig. 14) transversely elongated, crescentic, 375 to 450$\mu$ from the tip of the tail. Vagina (*vag.*, fig. 14) about 150$\mu$ long. Combined length of muscular portions of ovijectors (*ovij.*, fig. 14) at least 200$\mu$. Eggs ellipsoidal, 90 to 100$\mu$ long by about 50$\mu$ wide; in course of segmentation when laid.

HOSTS.—*Cattle (*Bos taurus*); *sheep (*Ovis aries*); *goat (*Capra hircus*); Dorcas gazelle (*Gazella dorcas*); white oryx (*Oryx leucoryx*); chamois (*Rupicapra rupicapra*); roe deer (*Capreolus capreolus*); fallow deer (*Dama dama*); stag (*Cervus elaphus*); argali (*Ovis ammon*).

Location.—Large intestine, rarely other parts of alimentary tract.

Localities collected.—Europe, United States, Africa, South America, Asia, Australia.

This species appears to be comparatively harmless. Its food consists of the vegetable material in the contents of the large intestine. The buccal capsule is commonly found filled with such material.

### Genus EUCYATHOSTOMUM Molin, 1861.

1861: *Eucyathostomum* Molin, 1861a, pp. 435, 455–463.

Generic diagnosis.—Strongylinæ (p. 26): Buccal capsule large, with wide anterior opening whose border is armed internally with a crown of numerous, slender, acutely pointed processes. Bursa with dorsal lobe projecting posteriorly beyond the lateral lobes. Ventral rays of each lateral lobe close together, united proximally and may present the appearance of an undivided ray. The ventral rays and the three lateral rays of each lateral lobe come off from a common trunk. The externo-dorsal ray is widely separated from the lateral rays, and originates from the dorsal trunk, or from one of the paired dorsal rays near its origin. Two long parallel dorsal rays, giving off two branches externally. The dorsal rays may present the appearance of being fused in the median line to form a single dorsal ray, with a bipartite tip. Three external branches are given off by the dorsal ray, the proximal one of which is the externo-dorsal ray. Spicules long, slender, equal. Vulva of female a short distance in front of the anus.

Type species.—*Eucyathostomum longesubulatum* Molin, 1861.

Two species of *Eucyathostomum* occur in the alimentary tract of ruminants, neither of which has been found in the United States.

KEY TO SPECIES OF EUCYATHOSTOMUM.

Externo-dorsal ray of male bursa originates at the root of the dorsal ray; male, 15 mm. long, female 21 mm. long.................. *Eucyathostomum spinulosum*, p. 40

Externo-dorsal ray of male bursa originates from the outer side of the dorsal ray some distance from its root; male 10 to 12 mm. long, female 15 to 20 mm. long. *Eucyathostomum longesubulatum*, p. 38

### **Eucyathostomum longesubulatum** Molin, 1861.

(Figs. 15–16.)

1861: *Eucyathostomum longesubulatum* Molin, 1861a, pp. 460–462, pl. 26, figs. 1, 2 (from intestine (cecum) of *Cervus campestris* [=*Blastocerus campestris*] and *Cervus rufus* [=*Mazama rufa*], Brazil).

1899: *Sclerostomum longesubulatum* (Molin) Stossich, 1899d, p. 113.

Specific diagnosis.—*Eucyathostomum* (p. 38): Head continuous with body. Mouth cavity cyathiform, cylindrical, with wide opening whose diaphanous circular border is armed externally with four larger spines or papillæ, internally with a crown of smaller processes. Body subcylindrical, straight, attenuated toward both ends. Anterior end truncate with inflated cuticle.

*Male* 10 to 12 mm. long by 0.3 mm. thick. Tail with wide copulatory bursa, obliquely truncated, prolonged in a triangular dorsal lobe, and supported by three systems of rays. The dorsal system gives off three rays from each side of the main trunk, which terminates in a bipartite tip. Each lateral trunk gives off four rays, the anterior of which is bifid. Spicules two, very long, filiform, acutely pointed.

*Female* 15 to 20 mm. long by 0.3 to 0.5 mm. thick. Tail long, subulate, scarcely curved. Anus remote from tip of tail. Vulva in posterior part of body near anus; its superior lip greatly inflated, rather protuberant. Uterus bicornate.

Hosts.—Pampas deer (*Blastocerus campestris*); red brocket (*Mazama rufa*).

Location.—Cecum.

Locality collected.—Brazil.

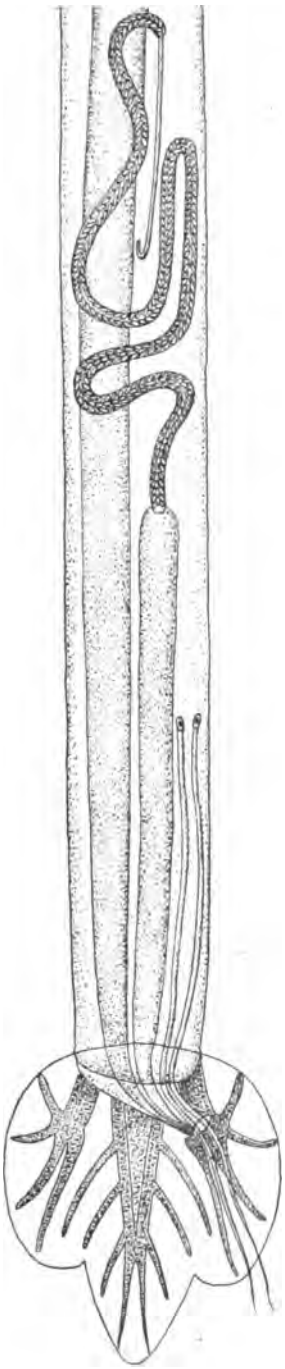

**Fig. 15.**—*Eucyathostomum longesubulatum.* Posterior end of body of male. Ventral view. Enlarged. (After Molin, 1861a, pl. 26, fig. 1.)

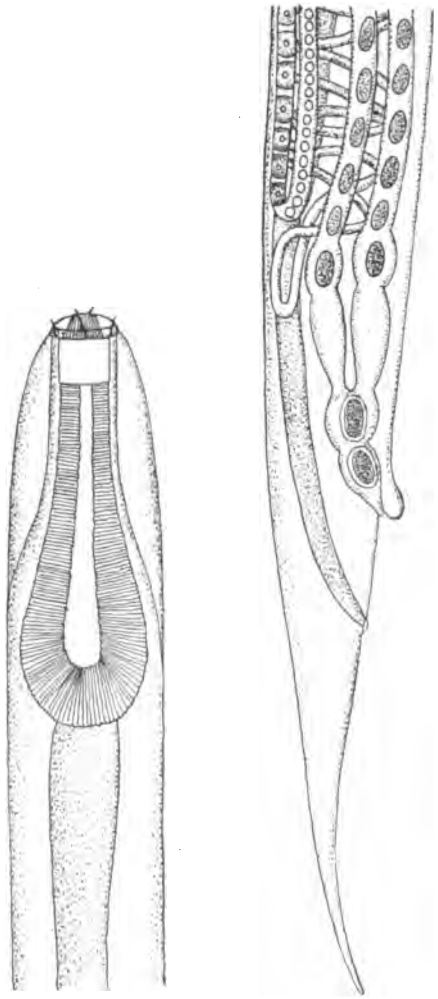

**Fig. 16.**—*Eucyathostomum longesubulatum.* Female. Anterior end of body at left. posterior end at right. Enlarged. (After Molin, 1861a, pl. 26, fig. 2.)

The foregoing diagnosis is based on the description and figures given by Molin (1861a). There are no later records of the occurrence of this species.

### **Eucyathostomum spinulosum** (Linstow, 1879) Railliet and Henry, 1909.

(Fig. 17.)

1879: *Strongylus* (?=*Eucyathostomum*) *spinulosus* Linstow, 1879b, pp. 331–332, pl. 5, fig. 17 (from intestine of *Capra ibex* L.)

1899: *Sclerostomum spinulosum* (Linstow) Stossich, 1899d, pp. 111–112.

1909: *Eucyathostomum spinulosum* (Linstow) Railliet and Henry, 1909b, p. 170.

Specific diagnosis.—*Eucyathostomum* (p. 38): Male 15 mm., female 21 mm. long. Thickness about 1 mm. in both sexes. Body spindle-shaped. Mouth opening provided with setæ on the border similar to *Eucyathostomum longesubulatum*. Buccal capsule large. Head without the larger spines described by Molin as present on the head of *E. longesubulatum*. Bursa five-lobed. The anterior lobes supported each by a single ray (?=prebursal papilla—B. H. R.). The lateral lobes have five rays, the four anterior of which originate close together. The unpaired posterior lobe (=dorsal lobe—B. H. R.) is supported by two parallel rays, each of which gives off two branches on its outer side.

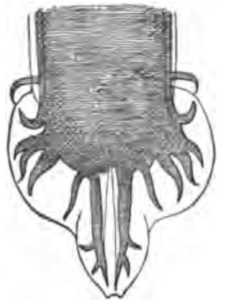

Fig. 17.—*Eucyathostomum spinulosum*. Bursa of male. Enlarged. (After Linstow, 1879b, pl. 5, fig. 17.)

Host.—Alpine ibex (*Capra ibex*).

Location.—Intestine.

Locality collected.—Europe.

Nothing is known concerning the species beyond the description given by Linstow (1879b), from which the foregoing diagnosis has been taken.

### Genus **ŒSOPHAGOSTOMUM** Molin, 1861.

1861: *Œsophagostomum* Molin, 1861a, pp. 435, 443–450.

Generic diagnosis.—Strongylinæ (p. 26): Adults 8 to 25 mm. in length, with head 75$\mu$ or more in diameter. Buccal capsule small. Attached to the chitinous framework of the buccal capsule inside the buccal cavity there are usually one or two crowns of delicate chitinous leaf-like processes. Cuticle surrounding the mouth usually inflated to form a ring-like mouth collar, which is sharply limited behind by a deep annular constriction. Six circum-oral papillæ—two lateral, two subdorsal, and two subventral—penetrating the mouth collar. Lateral papillæ short and thick, others longer and more slender. Excretory pore in front of the middle of the esophagus. At or in front of the excretory pore a transverse groove and a corresponding fold in the cuticle which extend round the body toward the dorsal surface. The cuticle between the mouth collar and the transverse groove usually inflated to form a vesicular swelling. Lateral membranous wings may be present beginning at the transverse groove and extending backward along the lateral lines. Cervical papillæ present. Bursa of male with two lateral lobes united by a smaller median lobe. In each lateral lobe six rays, namely, two ventral rays, three lateral rays, and one externo-dorsal ray. Ventral rays of equal size, parallel, close together. Mediolateral and postero-lateral rays parallel, close together. Dorsal ray (in median lobe) with two main branches, each of which is also divided into two unequal or subequal branches. Spicules more than 0.5 mm. long, slender, tubular, pointed; gubernaculum present, but not conspicuous. Prebursal papillæ present. Vulva, naked, a short distance in front of the anus. Eggs oval, with thin shells. Larval stages, in some cases at least, occur in nodules in the intestinal wall of the host. Adults free in the lumen of the intestine, usually the large intestine.

TYPE SPECIES.—*Œsophagostomum subulatum* Molin. 1861=*Œ. dentatum* (Rudolphi, 1803) Molin, 1861.

Three species of *Œsophagostomum* are known to occur in the alimentary tract of ruminants, and all three have been found in this country.

### KEY TO SPECIES OF ŒSOPHAGOSTOMUM.

1. Cervical papillæ near the middle of the esophagus; lateral membranes broad; spicules of male less than 1 mm. long; vulva about 1 mm. from the tip of the tail.......... 2

Cervical papillæ post-esophageal; lateral membranes very narrow; spicules of male 1.1 to 1.5 mm. long; vulva about 0.5 mm. from the tip of the tail; male 11 to 16 mm. long, female 13 to 24 mm. long........*Œsophagostomum venulosum*, p. 46

2. Mouth collar almost hemispherical; its height a little less than half its diameter, externo-lateral ray of bursa separted from the medio-lateral ray by a rather wide cleft; vulva not protuberant; male 12 to 16 mm. long, female 14 to 18 mm. long..........*Œsophagostomum columbianum*, p. 41

Mouth collar flattened, disk-like in shape, its height a little more than one-fourth its diameter; externo-lateral ray of the bursa closely approximated to the medio-lateral ray; stem of the lateral rays with a dorsal projection at the root of the postero-lateral ray; vulva protuberant; male 14 to 17 mm. long, female 16 to 22 mm. long..........*Œsophagostomum radiatum*, p. 44

### **Œsophagostomum columbianum** (Curtice, 1890) Stossich, 1899.

(Figs. 18-22.)

1890: *Œsophagostoma columbianum* Curtice, 1890c, pp. 16, 17, 20, 21, 22, 118, 145, 161, 165–180, pls. 24–27 (from sheep, United States).

1899: *Œsophagostomum columbianum* (Curtice) Stossich, 1899d, p. 96.

SPECIFIC DIAGNOSIS.—*Œsophagostomum* (p. 40): Length of body averages about 40 times its maximum thickness. Thickness of body nearly uniform in the middle three-fifths, becoming less toward both ends. Anterior portion of body commonly bent into a hook. Mouth collar (*m. c.*, fig. 19) hemispherical or truncate hemispherical in shape; its height a little less than half its diameter; two crowns of leaf-like processes, about twenty-four in each crown. Transverse cervical groove (*c. g.*, fig. 19) and its accompanying cuticular fold, well marked ventrally, become obliterated after crossing the lateral lines. Cuticle between the cervical groove and the head only very slightly inflated. Cervical papillæ (*c. p.*, fig. 19) in front of the middle of the esophagus. Well developed lateral membranes (*l. m.*, fig. 19) beginning at the cervical groove extend nearly the entire length of the body in both sexes.

*Male* 12 to 16 mm. long. Tips of the ventral (*v. v.*, *l. v.*, figs. 20, 21), medio-lateral (*m. l.*, figs. 20, 21), and postero-lateral (*p. l.*, figs. 20, 21) rays and the inner division (*i. d.*, fig. 20) of each of the two main branches of the dorsal ray (*d.*, figs. 20, 21) reach the edge of the bursa. Tips of the externo-dorsal (*e. d.*, figs. 20, 21) and externo-lateral (*e. l.*, figs. 20, 21) rays at about equal distances from the border of the bursa. Externo-lateral ray separated from the medio-lateral ray by a rather wide cleft. Distance between the tip of the externo-dorsal ray and the tip of the externo-lateral ray slightly greater than the distance between the latter and the tips of the ventral rays. Externo-dorsal rays take origin from the dorsal ray about halfway between its root and its bifurcation. Outer division of each main branch of the dorsal ray less than half as long as the inner division, but thicker. Spicules (*sp.*, fig. 20) 750 to 850$\mu$ in length. Gubernaculum about 100$\mu$ long.

*Female* 14 to 18 mm. long. Posterior 2 or 3 mm. of body tapers gradually to the pointed tip of the tail (fig. 22). Anus (*an.*, fig. 22) a little more than 0.3 mm. from the tip of the tail; vulva about 1 mm. Vulva (*vul.*, fig. 22) elliptical, transversely elongated

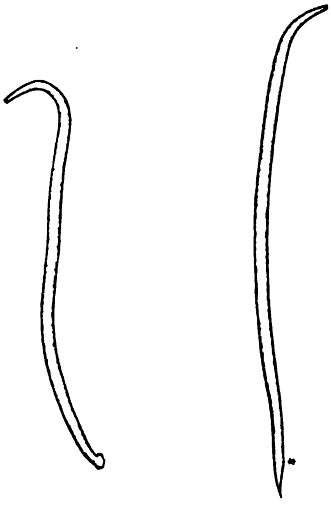

FIG. 18.—*Œsophagostomum columbianum.* Male at left, female at right. * Vulva. × 5. (Original.)

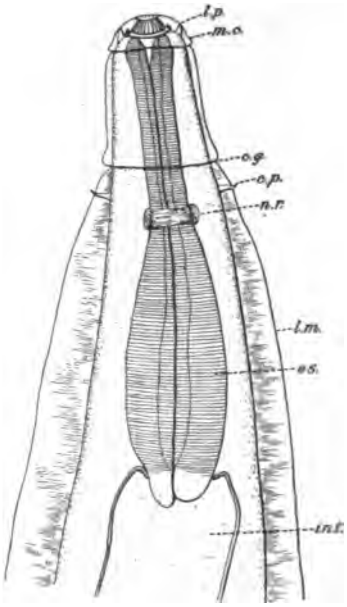

FIG. 19.—*Œsophagostomum columbianum.* Anterior end of body. Ventral view. *c. g.*, cervical groove; *c. p.*, cervical papilla; *es.*, esophagus; *int.*, intestine; *l. m.*, lateral membrane; *l. p.*, lateral circumoral papilla; *m. c.*, mouth collar; *n. r.*, nerve ring. × 75. (Original.)

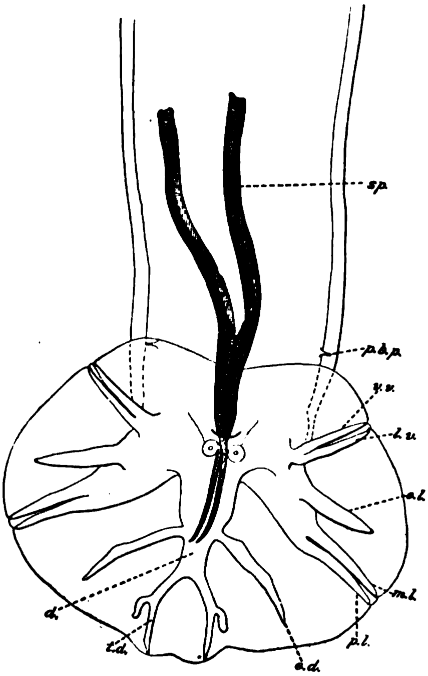

FIG. 20.—*Œsophagostomum columbianum.* Posterior end of body of male with bursa spread out. Ventral view. *d.*, dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. b. p.*, pre-bursal papilla; *p. l.*, postero-lateral ray; *sp.*, spicule; *t. d.*, terminal branch of dorsal ray; *v. v.*, ventro-ventral ray. × 75. (Original.)

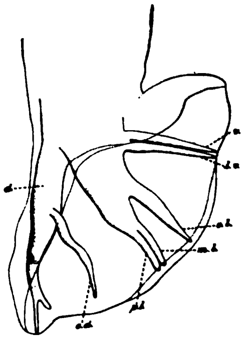

FIG. 21.—*Œsophagostomum columbianum.* Bursa of male viewed from right side. *d.*, dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *v. v.*, ventro-ventral ray. × 75. (Original.)

not raised above the surface of the body. Vagina (*vag.*, fig. 22) less than 100$\mu$ long. Combined length of the muscular portions of the two ovijectors (*ovij.*, fig. 22) including the sphincters about 230$\mu$. Eggs 65 by 40$\mu$ to 75 by 45$\mu$ in diameter.

HOSTS.—*Sheep (*Ovis aries*); *goat (*Capra hircus*); ?cattle (*Bos taurus*).

LOCATION.—Large intestine.

LOCALITIES COLLECTED.—United States, Australia.

This species is a very common parasite of sheep in the United States. It is the cause of the so-called nodular disease of the intestine. The nodules mark the location of larval stages of the parasite which live embedded in the wall of the intestine into which they penetrate after being swallowed by the host. In the early stage of the development of the larva the nodule is very small, but gradually increases in size, becoming filled with a mass of greenish cheesy material upon which, apparently, the larva feeds. When the larva has undergone a certain amount of growth and development it abandons the nodule and enters the lumen of the intestine, where it completes its development to maturity. The nodules are most common in the wall of the cecum, but may occur in other portions of the intestine and in the liver and other abdominal viscera.

Nodular disease is more or less injurious according to the extent of infestation, age, and individual vitality of the animals infested. Affected intestines are excluded from use as sausage casings.

There is no known effective medicinal treatment for this parasite. Lambs may be protected from serious infestation if raised by the so-called "bare-lot" method, in which the lambs and ewes are kept in inclosures free from vegetation, and fed and watered from racks and troughs arranged so that they can not be contaminated by the feces of the infested ewes.

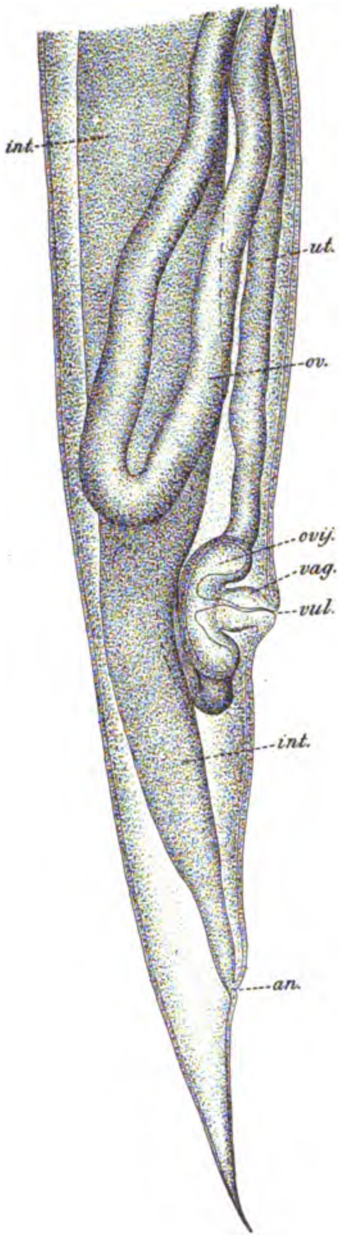

FIG. 22.—*Œsophagostomum columbianum.* Posterior end of body of female viewed from right side. *an.*, anus; *int.*, intestine; *ov.*, ovary; *ovij.*, ovijector; *ut.*, uterus; *vag.*, vagina; *vul.*, vulva. × 75. (Original.)

*Œsophagostomum columbianum* has been reported as a parasite of cattle, but the correctness of the identification seems questionable All of the specimens of *Œsophagostomum* from cattle which I have examined have been *Œ. radiatum.* In any event *Œ. columbianum*, if it occurs at all in cattle, is of rather rare occurrence in that host in this country.

### **Œsophagostomum radiatum** (Rudolphi, 1803) Railliet, 1898.

(Figs. 23-27.)

1803: *Strongylus radiatus* Rudolphi, 1803a, pp. 13-15 (from *Bos taurus*, Europe).

1866: *Strongylus inflatus* Schneider, 1866a, pp. 129, 131, 139, 141 (from *Bos taurus*) (not *S. inflatus* Molin, 1861a, pp. 520-521, pl. 5, figs. 7. 8; from *Myrmecophaga jubata*).

1884: *Strongylus dilatatus* Railliet, 1884. (*Strongylus inflatus* Schneider, 1866, renamed).

1885: *Œsophagostoma inflatum* (Schneider) Railliet, 1885a, pp. 346-347, fig. 235.

1896: *Œsophagostomum dilatatum* (Railliet) Railliet, 1896d, p. 160.

1896: *Œsophagostomum inflatum* (Schneider) Railliet, 1896d, p. 160.

1898: *Œsophagostomum radiatum* (Rudolphi) Railliet, 1898c, p. 254.

1906: *Œsophagostomum bovis* Schnyder, 1906b, pp. 182, 183, 197.

SPECIFIC DIAGNOSIS.—*Œsophagostomum* (p. 40): Length of body averages about 40 times its maximum thickness. Thickness of body nearly uniform in its middle three-fifths, becoming less toward both ends. Anterior end commonly bent into a hook. Mouth collar (*m. c.*, fig. 24) flattened, disk-like, its height a little more than one-fourth its diameter; a single crown of numerous small triangular denticles at the anterior border of the mouth capsule; leaf-like processes lacking. Cervical groove (*c. g.*, fig. 24) and cuticular fold well marked, continuing around the body, the fold projecting farther backward on the dorsal and ventral surfaces than on the lateral surfaces. Cuticle inflated (*c. i.*, fig. 24) between the mouth collar and the cervical groove. At about one-third the distance from the cervical groove to the head the inflated cuticle is constricted by a shallow annular groove (*c. a.*, fig. 24). Cervical papillæ (*c. p.*, fig. 24) opposite the middle of the esophagus. Well developed lateral membranes (*l. m.*, fig. 24) beginning at the cervical groove extend nearly the entire length of the body in both sexes. Lumen of esophagus has an infundibuliform enlargement at its beginning about 75μ long.

*Male* 14 to 17 mm. long. Tips of the ventral (*v. v.*, *l. v.*, figs. 25, 26), medio-lateral (*m. l.*, figs. 25, 26), and postero-lateral (*p. l.*, figs. 25, 26) rays, and the inner division (*i. d.*, figs. 25, 26) of each of the two main branches of the dorsal ray (*d.*, *figs.* 25, 26) reach the edge of the bursa. Tips of the externo-dorsal (*e. d.*, figs. 25, 26) and the externo-lateral (*e. l.*, figs. 25, 26) rays at about equal distances from the border of the bursa. Lateral rays come off from the external surface of their common stem (*l. t.*, figs. 25, 26) which projects dorsally, forming a protuberance (*d. h.*, figs, 25, 26) at the root of the postero-lateral ray. Externo-lateral ray closely approximated to the medio-lateral ray, separated from it by a narrow cleft. Distal portion of externo-lateral ray curved ventrally away from the medio-lateral ray. Distance between the tips of the externo-dorsal ray and the externo-lateral ray slightly greater than the distance between the latter and the tips of the ventral rays. Externo-dorsal rays take origin from the dorsal ray less than halfway between its root and its bifurcation. Outer division of each main branch of the dorsal ray less than one-half the length of the inner division. Spicules 700 to 800μ long. Gubernaculum about 115μ long.

*Female* 16 to 22 mm. long. Behind the vulva the body rapidly diminishes in thickness, then tapers more gradually to the tip of the slender tail (fig. 27). Tail curved ventralward. Anus (*an.*, fig. 27) a little more than 0.3 mm. from the tip of the tail; vulva about 1 mm. Vulva (*vul.*, fig. 27) elliptical, transversely elongated, raised on a prominently projecting rounded papilla. Vagina less than 150μ long. Combined

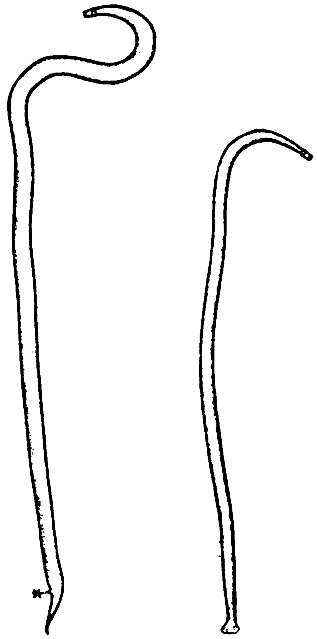

FIG. 23.—*Œsophagostomum radiatum*. Male at right, female at left. *Vulva. × 5. (Original.)

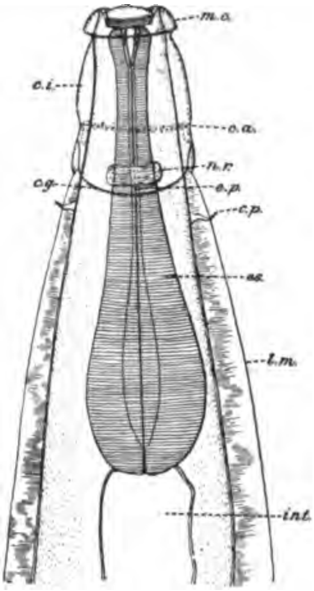

FIG. 24.—*Œsophagostomum radiatum*. Anterior end of body. Ventral view. *c. a.*, annular groove surrounding cervical inflation of cuticle; *c. g.*, cervical groove; *c. i.*, cervical inflation; *c. p.*, cervical papilla; *e. p.*, excretory pore; *es.*, esophagus; *int.*, intestine; *l. m.*, lateral membrane; *m. c.*, mouth collar; *n. r.* nerve ring. × 75. (Original.)

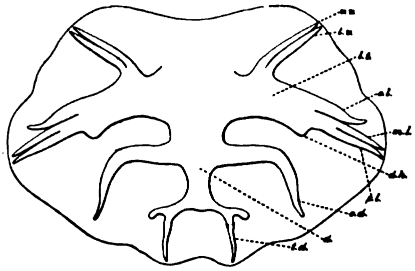

FIG. 25.—*Œsophagostomum radiatum*. Bursa of male spread out. *d.*, dorsal ray; *d. h.*, dorsal projection of trunk of lateral rays at base of postero-lateral ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *l. t.*, trunk of lateral rays; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *t. d.*, terminal branch of dorsal ray; *v. v.*, ventro-ventral ray. × 75. (Original.)

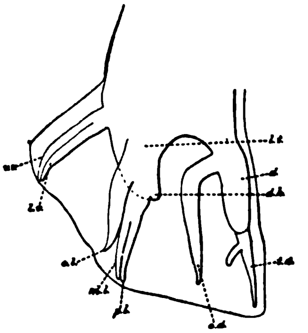

FIG. 26.—*Œsophagostomum radiatum*. Bursa of male, viewed from left side. *d.*, dorsal ray; *d. h.*, dorsal projection of trunk of lateral rays at base of postero-lateral ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. t.*, trunk of lateral rays; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *t. d.*, terminal branch of dorsal ray; *v. v.*, ventro-ventral ray. × 75. (Original.)

**length of the muscular portions of the two ovijectors (*ovij.*, fig. 27) including the sphincters about 250μ. Eggs (*e.*, fig. 27) 75 by 40μ to 85 by 45μ in diameter.**

Host.—* Cattle (*Bos taurus*).

**Location.—Large intestines.**

**Localities collected.—United States, Europe, Australia.**

In this species, as in *Œ. columbianum*, a portion of the larval stage is passed in nodules formed in the wall of the intestines. The location of the nodules is apparently more often the small intestine than the large intestine, just the opposite to *Œ. columbianum.*

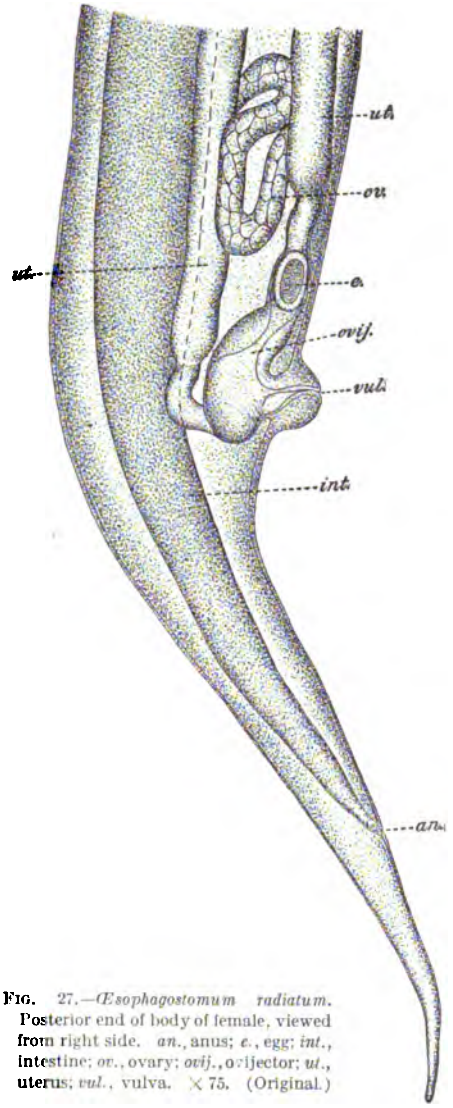

Fig. 27.—*Œsophagostomum radiatum.* Posterior end of body of female, viewed from right side. *an.*, anus; *e.*, egg; *int.*, intestine; *ov.*, ovary; *ovij.*, ovijector; *ut.*, uterus; *vul.*, vulva. × 75. (Original.)

## **Œsophagostomum venulosum** (Rudolphi, 1809) Railliet, 1896.

(Figs. 28-32.)

1809: *Strongylus venulosus* Rudolphi, 1809a, pp. 221-222 (from *Capra hircus*, Europe).

1819: *Strongylus ammonis* Rudolphi, 1819a, p. 37.

1845: *Strongylus radiatus* Rudolphi of Dujardin, 1845a, pp. 125-126 (in part).

1851: *Strongylus contortus* Rudolphi of Diesing, 1851a, p. 318 (misdetermination).

1861: *Œsophagostomum acutum* Molin, 1861a, p. 449.

1885: *Œsophagostoma venulosum* (Rudolphi) Railliet, 1885a, pp. 347-348.

1887: *Œsophagostoma inflatum* var. *ovis* Carita, 1887a, p. 60.

1896: *Œsophagostomum venulosum* (Rudolphi) Railliet, 1896m, p. 490.

Specific diagnosis.—*Œsophagostomum* (p. 40): Length of body 30 to 35 times its maximum thickness. Thickness of body nearly uniform in the middle three-fifths, becoming less toward both ends. Anterior end of body usually straight. Height of mouth collar (*m. c.*, fig. 29) about one-third its diameter; shape truncate conical; two crowns of leaf-like processes; not more than 16 processes in each crown. Cervical groove (*c. g.*, fig. 29) usually does not extend dorsal of the lateral lines, but may in some cases be traced entirely around the body. Cuticle of neck inflated (*c. i.*, fig. 29) between the mouth collar and the cervical groove. Cervical papillæ (*c. p.*, fig. 29) post-esophageal. Lateral membranes (*l. m.*, fig. 29) extend nearly the entire length of the body, but are very narrow throughout their course.

*Male* 11 to 16 mm. long. Tips of the ventral (*v. v.*, *l. v.*, figs. 30, 31), medio-lateral (*m. l.*, figs. 30, 31), and postero-lateral (*p. l.*, figs. 30 , 31) rays, and the inner division (*i. d.*, fig. 30)) of each of the two main branches of the dorsal ray (*d.*, figs. 30, 31) reach the edge of the bursa. Tips of the externo-dorsal (*e. d.*, figs. 30, 31) and externo-lateral (*e. l.*, figs. 30, 31) rays at about equal distances from the edge of the bursa. Externo-lateral ray separated from the medio-lateral ray by a rather wide cleft. Distance between the tip of the externo-dorsal ray and the tip of the externo-lateral ray slightly less than the distance between the latter and the tips of the ventral rays. Externo-dorsal rays take origin from the dorsal ray about halfway between its root and its bifurcation. Outer division of each main branch of the dorsal ray about half as long as the inner division, and reaching nearly to the border of the bursa. Spicules (*sp.*, fig. 31) 1.1 to 1.5 mm. long. Gubernaculum 90 to 100μ long.

*Female* 13 to 24 mm. long. Body tapers from a short distance in front of the vulva to the tip of the sharply pointed tail, which is commonly bent dorsalward. Anus (*an.*, fig. 32) 150 to 200μ, vulva 375 to 500μ, from the tip of the tail. Vulva (*vul.*, fig. 32) elliptical, transversely elongated, more or less protuberant. Vagina (*vag.*, fig. 32) 400 to 600μ long. Combined length of the muscular portions of the two ovijectors (*ovij.*, fig. 32) including the sphincters 250 to 300μ. Eggs 85 by 45μ to 100 by 55μ in diameter.

HOSTS.—* Goat (*Capra hircus*); * sheep (*Ovis aries*); * fallow deer (*Dama dama*); roe deer (*Capreolus capreolus*); argali (*Ovis ammon*); chamois (*Rupicapra rupicapra*); Arabian camel (*Camelus dromedarius*).

LOCATION.—Large intestine, more rarely small intestine and stomach.

LOCALITIES COLLECTED.—Europe and United States.

This species, commonly reported as a parasite of sheep and goats in Europe, is much less common in those hosts in this country than *Œ. columbianum*.

### Subfamily METASTRONGYLINÆ[1] Leiper, 1908.

SUBFAMILY DIAGNOSIS.—Strongylidæ (p. 26): Mouth cavity very small, not enlarged to form a buccal capsule.

TYPE GENUS.—*Metastrongylus* Molin, 1861.

Five genera of this subfamily are represented among the nematodes parasitic in the alimentary tract of ruminants.

#### KEY TO GENERA OF METASTRONGYLINÆ.

(The imperfectly known species (?*Hæmonchus*) *bispinosus*, p. 54, *Strongylus ventricosus*, p. 98, and *Strongylus fordii*, p. 99, though evidently belonging in the subfamily Metastrongylinæ, are not included in this and following keys.)

1. Mouth cavity containing a single buccal tooth or lancet; well developed cervical papillæ or spines present; bursa of male with two large lateral lobes, and a small asymmetrical dorsal lobe; gubernaculum present; both sexes 10 mm. or more in length........................................*Hæmonchus*, p. 49

   No buccal teeth or lancets in mouth cavity; cervical papillæ present or absent; dorsal lobe or dorsal lobules of bursa symmetrical in position; gubernaculum of spicules present or absent.......................................... 2

2. Tip of latero-ventral ray of bursa closer to tip of externo-lateral ray than to tip of ventro-ventral ray; ventro-ventral ray much smaller than latero-ventral ray; head about 10μ in diameter; both sexes less than 10 mm. in length; cervical papillæ absent; spicules less than 200μ long; gubernaculum present. *Trichostrongylus*, p. 86

   Tip of latero-ventral ray of bursa closer to tip of ventro-ventral ray than to tip of externo-lateral ray.............................................. 3

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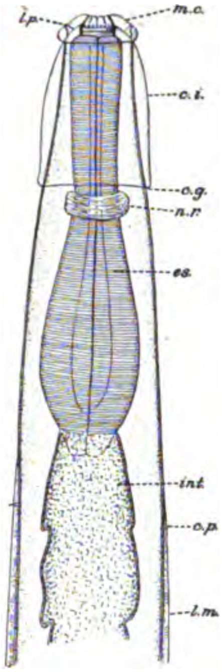
[1] See Addendum, p. 124.



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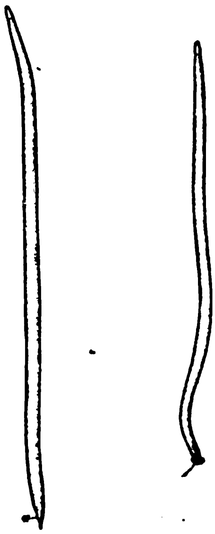

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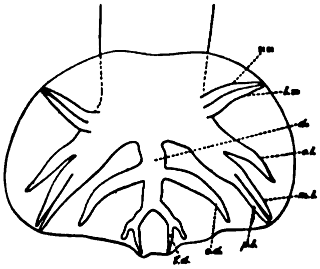

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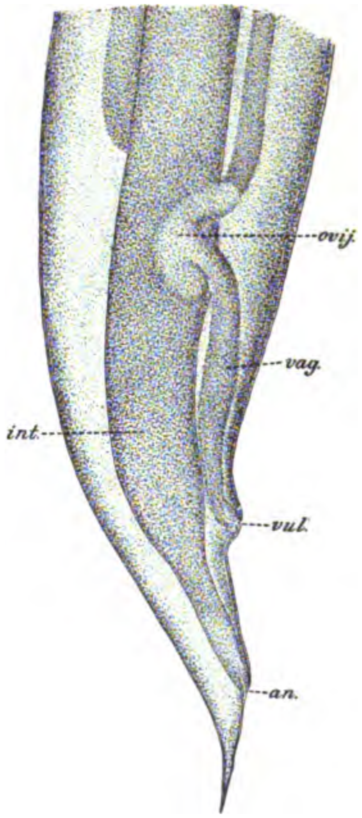

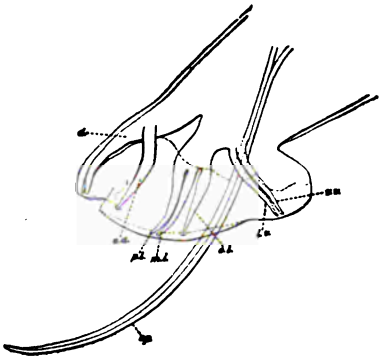

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32

Legends for figures 28 to 32 at foot of facing page.

3. Head less than 25μ in diameter; cervical papillæ present; tips of ventro-ventral and latero-ventral rays of each lateral lobe of bursa close together; a small accessory bursal membrane attached to the posterior end of the body toward its dorsal side, inside the bursa; gubernaculum present or absent........*Ostertagia*, p. 54
Head over 25μ in diameter; cervical papillæ absent; no accessory bursal membrane; gubernaculum lacking................ ................................ 4

4. Ventro-ventral and latero-ventral rays of each lateral lobe of bursa close together, parallel; 2 dorsal rays; dorsal lobe of bursa divided into two lobules each supported by one of the dorsal rays; spicules tubular, filiform, over 0.5 mm. long..............................................*Nematodirus*, p. 82
Ventro-ventral and latero-ventral rays of bursa divergent, their tips rather widely separated; unpaired median dorsal ray divides distally into two branches, parallel or forming a lyre-shaped structure; spicules short, thick, less than 0.5 mm. long..............................................*Cooperia*, p. 69

### Genus **HÆMONCHUS** Cobb, 1898.

1898: *Hæmonchus* Cobb, 1898a, p. 447.

GENERIC DIAGNOSIS.—Metastrongylinæ (p. 47): Head less than 50μ in diameter, with inconspicuous circumoral papillæ. The small mouth cavity contains a slender tooth or lancet originating from the dorsal side of its base. Cuticle of head and neck not inflated. A well developed cervical spine in each lateral line of the body in the esophageal region. Bursa of male with large lateral lobes and a small dorsal lobe not in the median line but attached to one of the lateral lobes near its base. Dorsal ray supporting the dorsal lobe divided distally into two branches. Six rays in each lateral lobe. Ventral rays of each lateral lobe separated distally, curving forward. Medio-lateral and postero-lateral rays distally curve backward or dorsalward away from the externo-lateral ray. Externo-dorsal ray long and slender. Prebursal papillæ present. Spicules relatively short, less than 1 mm. long. Gubernaculum present. Vulva of female in posterior portion of the body covered by a prominent linguiform process which projects backward. Ovijectors well developed. Eggs ellipsoidal, with thin shells.

TYPE SPECIES.—*Hæmonchus contortus* (Rudolphi, 1803) Cobb, 1898.

Two species belonging to the genus *Hæmonchus* are represented among the nematodes parasitic in ruminants, to which a third of uncertain identity has been provisionally added by Railliet and Henry (1909a).

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FIG. 28.—*Œsophagostomum venulosum*. Male at right, female at left. * Vulva. × 5. (Original.)

FIG. 29.—*Œsophagostomum venulosum*. Anterior end of body. Ventral view. *c. g.*, cervical groove; *c. i.*, cervical inflation; *c. p.*, cervical papilla; *es.*, esophagus; *int.*, intestine; *l. m.*, lateral membrane; *l. p.*, lateral circum-oral papilla; *m. c.*, mouth collar; *n. r.*, nerve ring. × 75. (Original.)

FIG. 30.—*Œsophagostomum venulosum*. Bursa of male spread out. *d.* dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *t. d.*, terminal branch of dorsal ray; *v. v.*, ventro-ventral ray. × 75. (Original.)

FIG. 31.—*Œsophagostomum venulosum*. Bursa of male viewed from right side. *d.*, dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *sp.*, spicules; *v. v.*, ventro-ventral ray. × 75. (Original.)

FIG. 32.—*Œsophagostomum venulosum*. Posterior end of body of female viewed from right side. *an.*, anus; *int.*, intestine: *ovij.*, ovijector; *vag.*, vagina; *vul.*, vulva. × 75. (Original.)

KEY TO SPECIES OF HÆMONCHUS.

(The imperfectly known (?*Hæmonchus*) *bispinosus*, p. 54, is not included in this key.)

Stem of the ray of the asymmetrical dorsal lobe of the bursa less than twice as long as its branches; spicules of male 300 to 500μ long; male 10 to 20 mm. long, female 18 to 30 mm. long........................*Hæmonchus contortus*, p. 50.

Stem of the ray of the asymmetrical dorsal lobe of the bursa twice as long as its branches; spicules of male about 625μ long; male 20 to 21 mm. long, female 26 to 29 mm. long......................................*Hæmonchus longestipes*, p. 54.

### **Hæmonchus contortus** (Rudolphi, 1803) Cobb, 1898.

(Figs. 33-37.)

1803: *Strongylus contortus* Rudolphi, 1803a, pp. 15-17 (from *Ovis aries*, Europe).

1861: *Strongylus filicollis* Rudolphi of Molin, 1861a, pp. 512-513 (misdetermination).

1893: *Strongylus placei* Place, 1893, Vet. Rec., Lond. (250), v. 5, Apr. 22, p. 589 ("strongyle-like worms 1-3 centimeters in length" from the abomasum of a calf).

1898: *Hæmonchus contortus* (Rudolphi) Cobb, 1898a, p. 447, fig. 120.

Specific diagnosis.—*Hæmonchus* (p. 49): Head (fig. 34) about 30μ in diameter. Buccal lancet 10 to 15μ long may project slightly through the opening of the mouth. Cervical spines (*c. p.*, fig. 34) about 0.3 mm. from the anterior end of the body. Esophagus (*es.*, fig. 34) claviform, about 1.5 mm. long. Diameter of body at base of esophagus about 180μ.

*Male* 10 to 20 mm. long. Maximum thickness about 400μ in the posterior portion of the body, some distance in front of the bursa. Anteriorly the body is gradually attenuated. Lateral lobes of bursa (fig. 35) large, 600 to 700μ long by 300 to 400μ wide. The asymmetrically situated dorsal lobe is attached to the left lateral lobe on its inner side near its base and measures about 150μ long by 125μ wide. Dorsal ray (*d.*, fig. 35) supporting the dorsal lobe, distally divides into two branches, each of which is bifurcated at its extremity. Stem of dorsal ray slightly longer than its branches. Dorsal ray takes its origin from the left common trunk of the rays, near the point of origin of the left externo-dorsal ray. Paired rays parallel and close together for some distance beyond their origin from the common trunk. Ventral rays fused proximally are separated distally, curving ventralward, and both extending nearly to the edge of the bursa. The ventro-ventral ray (*v. v.*, fig. 35) is narrower than the latero-ventral ray (*l. v.*, fig. 35) and shorter. The lateral rays originate from the common trunk in a common stem dividing distally into three. The externo-lateral ray (*e. l.*, fig. 35) is almost straight, extending nearly to the edge of the bursa. The latero-ventral and externo-lateral rays are about equal in thickness, thicker than any of the other rays. The medio-lateral (*m. l.*, fig. 35) and postero-lateral (*p. l.*, fig. 35) rays curve dorsalward in their distal portion, diverging from one another slightly at their tips and nearly reaching the edge of the bursa. Externo-dorsal ray (*e. d.*, fig. 35), slenderest and longest of the rays, nearly straight, slightly curved dorsalward in its distal portion, originates from the common trunk of the rays near the base of the lateral lobe of the bursa. It reaches nearly to the edge of the bursa, but its tip is usually at a slightly greater distance from the edge than the tips of the other rays. The tips of the medio-lateral and postero-lateral rays are closer together than the tips of any other two contiguous rays; tips of the ventral rays next, then the tips of the postero-lateral and externo-dorsal rays, and finally the tips of the externo-lateral and latero-ventral are more widely separated than the tips of any other two contiguous rays. Spicules (*sp.*, fig. 35) 300 to 500μ long, reduced in size from before backward, with small knobbed tips; left spicule with a barb-like projection about 20μ from the posterior end, right spicule with a similar projection about 40μ from the posterior end. Gubernaculum (*gub.*, fig. 35) about 200μ long by 25 to 30μ broad, flat, fusiform, with thickened edges.

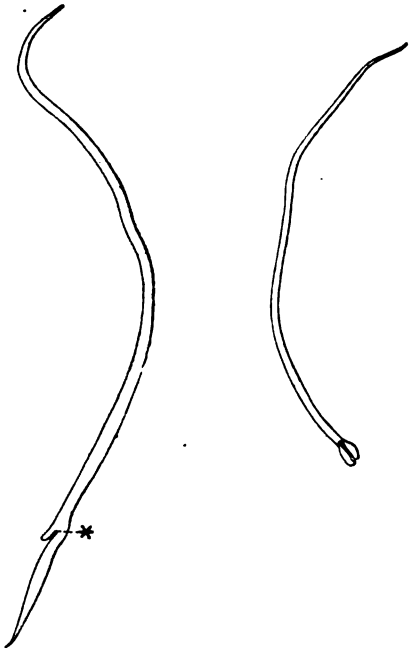


FIG. 33.—*Hæmonchus contortus*. Male at right, female at left. * Vulva. × 5. (Original.)

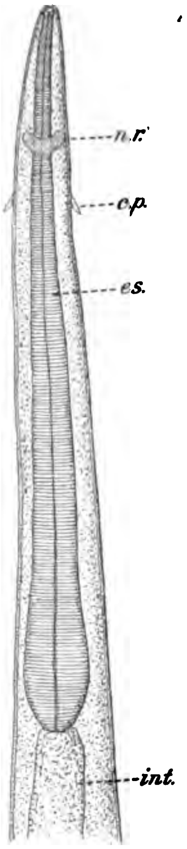


FIG. 34.—*Hæmonchus contortus*. Anterior end of body. *c. p.*, cervical papilla; *es.*, esophagus; *int.*, intestine; *n. r.*, nerve ring. × 75. (Original.)

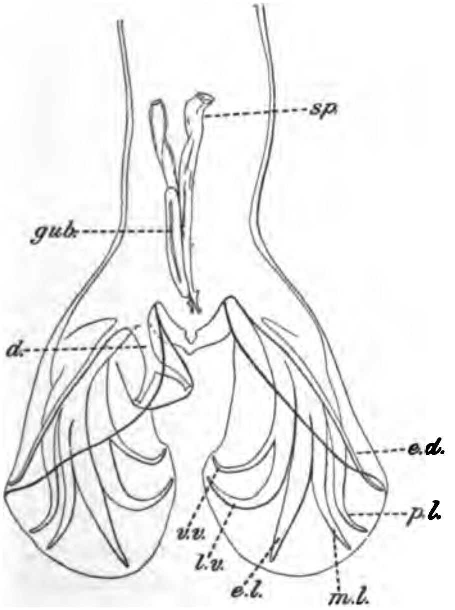


FIG. 35.—*Hæmonchus contortus*. Posterior end of body of male. Dorsal view. *d.*, dorsal ray supporting the asymmetrically situated dorsal lobe of bursa; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *gub.*, gubernaculum; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *sp.*, spicule; *v. v,.* ventro-ventral ray. × 75. (Original.)

*Female* 18 to 30 mm. long by about 0.5 mm. in maximum thickness a short distance in front of the vulva. Body more gradually attenuated toward the anterior extremity than toward the posterior extremity. Vulva (*vul.*, fig. 36) 3 to 4.5 mm. from the tip of the tail, covered by a prominent backward projecting linguiform process (*lab.*, fig. 36) about 0.5 mm. long. Combined length of muscular portions of ovijectors (*ovij.*, fig. 36), including the sphincters, about 1 mm. Ovaries (*ov.*, figs. 36, 37) wound spirally around the intestine. Anus (*an.*, fig. 37) 400 to 630$\mu$ from the tip of the tail. Tail slender, acutely pointed, diameter at anus about 100$\mu$. Eggs 75 to 95$\mu$ long by 40 to 50$\mu$ wide, segmenting when laid.

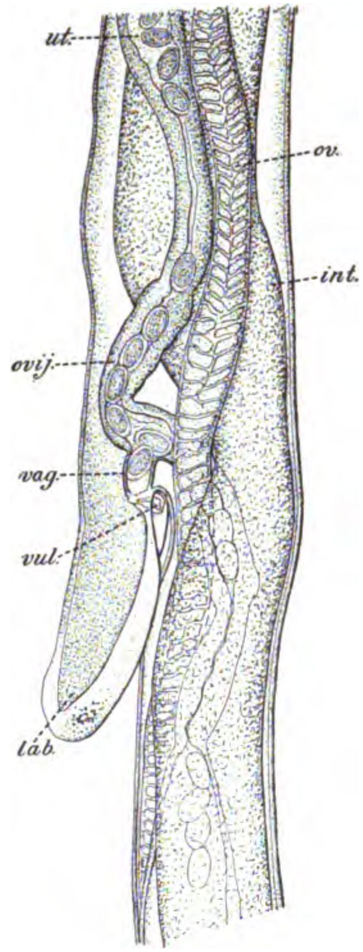


FIG. 36.—*Hæmonchus contortus.* Body of female in region of vulva, viewed from left side. *int.*, intestine; *lab.*, linguiform process covering vulva; *ov.*, ovary; *ovij.*, ovijector; *ut.*, uterus; *vag.*, vagina; *vul.*, vulva. × 75. (Original.)

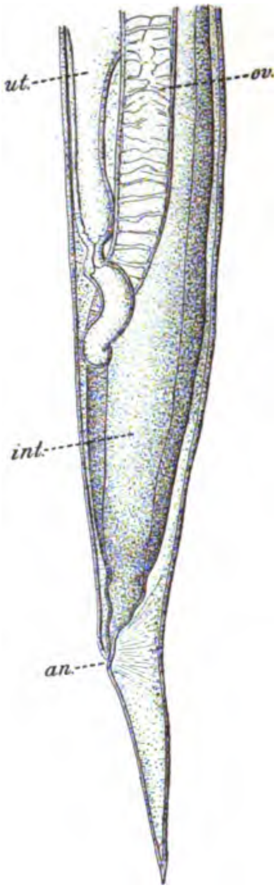


FIG. 37.—*Hæmonchus contortus.* Posterior end of body of female, viewed from left side. *an.*, anus; *int.*, intestine; *ov.*, ovary; *ut.*, uterus. × 75. (Original.)

HOSTS.—*Cattle (*Bos taurus*): *sheep (*Ovis aries*); *goat (*Capra hircus*); addax (*Addax nasomaculatus*); *moose (*Alce americanus*); *prong-horned antelope (*Antilocapra americana*); chamois (*Rupicapra rupicapra*); *American bison (*Bison bison*); *roe deer (*Capreolus capreolus*); *mule deer (*Odocoileus hemionus*); *deer (*Mazama* sp.);

man (*Homo sapiens*); *bharal (*Ovis nahura*); argali (*Ovis ammon*); *Mexican mountain sheep (*Ovis mexicana*); *Newfoundland caribou (*Rangifer terrænovæ*).

LOCATION.—Fourth stomach, more rarely other compartments of the stomach, and intestine.

LOCALITIES COLLECTED.—Europe, United States, Asia, Africa, Australia, South America, New Zealand.

*Hæmonchus contortus* is one of the commonest parasites of sheep, and when numerous is very injurious. It evidently feeds upon the blood of its host, attacking the mucous membrane of the fourth stomach by means of its buccal tooth. Heavy infestation leads to anemia, dropsy, emaciation, and irregularities of digestion. Many lambs are killed every year by this parasite.

In another paper (Ransom, 1906i, B. A. I. Circular 93) it has been shown that *Hæmonchus contortus* undergoes a direct development without intermediate host. The eggs passed in the feces of the host hatch in a few hours, days, or weeks, according to the temperature. Dryness or a freezing temperature kills the eggs and newly hatched larvæ in a short time. The newly hatched larva has an esophagus with a posterior bulb containing a masticatory apparatus, and it feeds upon the fecal matter in which it lives. Within a few days or weeks, the length of time required varying according to the temperature, the larva develops into the final free-living stage, which has a simple claviform esophagus without posterior bulb. In this stage the larva is closely enveloped by a thin chitinous sheath, and apparently is no longer able to ingest food, depending for its nourishment upon material stored up in the cells of the intestine. The ensheathed larva is motile at temperatures above 40° F., and becomes more active as the temperature becomes higher. Unlike newly hatched larvæ and eggs, the ensheathed larva can withstand freezing and drying for long periods, and may survive several months in the dried condition, afterwards reviving on the addition of moisture. When the air is sufficiently damp for moisture to be precipitated as dew or rain, the ensheathed larvæ crawl up grass blades or other objects, coming to rest when the moisture evaporates and resuming their migration when the air again becomes damp, and thus gradually work their way higher and higher from the ground. When swallowed by a sheep or other ruminant the ensheathed larva continues its development toward maturity and becomes a full grown adult in two or three weeks.

Methods of treatment of sheep infested with this parasite are described in B. A. I. Circular 102 (Ransom, 1907b).

The best means of controlling this parasite seems at present to be the rotation of pastures, changing the flock to fresh pasture as frequently as possible, taking care not to overstock, and keeping sheep and cattle out of each pasture for at least a year before it is used again, so that infection in the pasture may have time to die out.

*Hæmonchus contortus* has been reported once as a parasite of man in South America, but this undoubtedly was a purely accidental occurrence. It does not occur in horses, rabbits, or pigs, and is clearly a parasite which is normally restricted to ruminants. Pastures from which sheep and cattle have been removed in order for infection to die out may accordingly be used for horses and pigs without danger of keeping up the infection.

### **Hæmonchus longistipes** Railliet and Henry, 1909.

1909: *Hæmonchus longistipes* Railliet and Henry, 1909a, p. 86 (from *Camelus dromedarius*, Africa, India).

SPECIFIC DIAGNOSIS.—*Hæmonchus* (p. 49): *Male* 20 to 21 mm. long. Spicules 625μ long. Bursa with an asymmetrical dorsal lobe supported by a ray whose trunk is twice as long as its distal branches.

*Female* 26 to 29 mm. long.

HOST.—Arabian camel (*Camelus dromedarius*).

LOCATION.—Fourth stomach.

LOCALITIES COLLECTED.—Africa and India.

The foregoing diagnosis is taken from the brief description of Railliet and Henry (1909a).

### (?**Hæmonchus) bispinosus** (Molin, 1860) Railliet and Henry, 1909.

1860: *Strongylus bispinosus* MOLIN, 1860e, p. 351 (from *Cervus nambi* (= *Mazama nana*], Brazil).

1909: (*?Hæmonchus*) *bispinosus* (Molin) Railliet and Henry, 1909a, p. 86.

SPECIFIC DIAGNOSIS.—*Hæmonchus* (p. 49): Head continuous with the body, not alate. Mouth with unarmed border. Body filiform; anterior end of body gradually attenuated, with two strong cervical spines.

*Male* 10 mm. long by 0.2 mm. thick. Tail of male curved, provided with a trilobed copulatory bursa. Lateral lobes very long, supported by 5 rays, the middle one of which is straight; the other rays diverge from the middle ray, and are curved at the tips. Median lobule of bursa with two rays. Spicules with long styloid shanks. Sheath of spicules very long, filiform.

*Female* 17 mm. long by 0.3 mm. thick. Tail long, subulate. Anus remote from tip of tail. Vulva in posterior portion of body, large, bilabiate, with limbiform anterior lip, and pendulous posterior lip, swollen to form a large vesicle. Uterus bicornate.

HOST.—Pygmy brocket (*Mazama nana*).

LOCATION.—Stomach.

LOCALITY COLLECTED.—Brazil.

Nothing is known concerning this species beyond the brief descriptions given by Molin (1860e, 1861a, p. 514) from which the foregoing diagnosis is taken.

### Genus OSTERTAGIA Ransom, 1907.

1907: *Ostertagia* Ransom, 1907k, p. 2.

GENERIC DIAGNOSIS.—Metastrongylinæ (p. 47): Head less than 25μ in diameter, with six indistinct lips or papillæ surrounding the mouth. Mouth cavity small. Cervical papillæ present. Cuticle marked with 25 to 35 longitudinal ridges appearing as simple lines, except under high magnification when they sometimes show a finely beaded appearance. Cuticle of head may be slightly dilated, forming a narrow collar or annulus. Bursa with two lateral lobes united by a smaller median lobe. Each lateral lobe supplied with six supporting rays. The two ventral rays are close together and their tips are in relation with a more or less conspicuous indentation of the edge of the bursa. The tips of the medio-lateral, postero-lateral and externo-dorsal rays are in relation with the posterior border of the bursa. The dorsal ray separates into two main branches which may divide distally into two short branches or give off one or two short side branches internally or externally. Attached to the posterior end of the body of the male toward the dorsal side and inside the bursa there is an accessory bursal membrane with a free posterior edge supported by two slender diverging rays. The spicules are short (less than 1 mm. in length), similar in size and shape, and are divided lengthwise in the distal portion into two or three processes. An accessory piece or gubernaculum may be present or absent. When present it is inconspicuous, colorless and drawn out into a slender process posteriorly. Prebursal papillæ present. Vulva less than one-fifth the length of the body from the posterior end, naked or covered by a thin, backward projecting, cuticular flap. Ovijectors well developed. Eggs oval, with thin shells.

TYPE SPECIES.—*Ostertagia ostertagi* (Stiles, 1892) Ransom, 1907.

Seven species of *Ostertagia* are known to occur in ruminants, and all but one of these have been found in America.

### KEY TO SPECIES OF OSTERTAGIA.

1. Spicules of male about 700$\mu$ long; tail of female bluntly pointed; male 6.5 to 7.5 mm. long, female 8 to 10 mm. long.....................*Ostertagia mentulata*, p. 68
   Spicules of male less than 400$\mu$ long........................................ 2
2. Spicules of male 150 to 180$\mu$ long; bursa about 300$\mu$ wide when both wings are spread out; latero-ventral ray thickest of the rays; stem of dorsal ray 40 to 50$\mu$ long; branches 35 to 40$\mu$ long; male 6.5 to 7 mm. long..*Ostertagia trifurcata*, p. 62
   Spicules of male over 200$\mu$ in length........................................ 3
3. Stem of dorsal ray of bursa five times as long as its two main branches; spicules 210$\mu$ long; male 4.5 to 5 mm. long, female 6 to 7 mm. long. *Ostertagia brigantiaca*, p. 69
   Stem of dorsal ray less than three times as long as its two main branches...... 4
4. Bursa over 0.5 mm. in width, when both wings are spread out; dorsal ray over 200$\mu$ long........................................................ 5
   Bursa less than 0.5 mm. in width, when both wings are spread out; dorsal ray less than 100$\mu$ long................................................... 6
5. Spicules of male 250 to 280$\mu$ long, rather delicate in structure, light yellowish-brown; gubernaculum absent; male 10 to 13 mm. long, female 12 to 20 mm. long; eggs large, 160 to 200$\mu$ long............................*Ostertagia marshalli*, p. 62
   Spicules of male 290 to 320$\mu$ long, strongly built, dark yellowish-brown; gubernaculum present, about 120$\mu$ long; male 12 to 16 mm. long. *Ostertagia occidentalis*, p. 67
6. Main branches of dorsal ray of bursa bifid at the tip, without secondary branches; spicules 220 to 230$\mu$ long; gubernaculum about 65$\mu$ long; tail of female terminates in a rather acute point without annular striations near the tip; male 6.5 to 7.5 mm. long, female 8.3 to 9.2 mm. long.......*Ostertagia ostertagi*, p. 56
   Main branches of the dorsal ray with a small, short, secondary branch externally and one internally in the distal portion, the latter near the tip; spicules 280 to 320$\mu$ long; gubernaculum about 90$\mu$ long; tail of female terminating in a rather blunt rounded point, slightly swollen a short distance from the tip and in this region marked by 3 to 5 annular striations; male 7.5 to 8.5 mm. long, female 9.8 to 12.2 mm. long...........................*Ostertagia circumcincta*, p. 59

### **Ostertagia ostertagi** (Stiles, 1892) Ransom, 1907.

(Figs. 38-43.)

1890: *Strongylus convolutus* Ostertag, 1890b, pp. 457–460 (not *S. convolutus* Kuhn, 1829).

1892: *Strongylus ostertagi* Stiles, 1892e, pp. 147–148 (*S. convolutus* Ostertag, 1890 [not Kuhn, 1829] renamed).

1893: *Strongylus sp.* Harker, 1893, Agric. Students' Gaz., Cirencester, n. s., v. 6 (4), Aug., pp. 94–97, figs. 1–5 (in part, fig. 2 evidently drawn from a male of *O. ostertagi*).

1899: *Strongylus cervicornis* of Gilruth, 1899a, p. 25 (misidentification).

1901: *Strongylus harkeri* Stödter, 1901a, pp. 72, 75, 91, pl. 11, figs. 1–5 (in part).

1907: *Ostertagia ostertagi* (Stiles, 1892) Ransom, 1907k, p. 2.

Specific diagnosis.—*Ostertagia* (p. 54): *Male* 6.5 to 7.5 mm. long. Maximum thickness 115 to 130μ just in front of bursa. Diameter of head 16 to 18μ; diameter of body at level of nerve ring 40 to 45μ, at base of esophagus 60 to 75μ. Esophagus 650 to 680μ in length, surrounded by a nerve ring at a distance of 265 to 280μ from the anterior end. The excretory pore is situated about 300μ and the cervical papillæ 340μ from the anterior end of the body. The esophagus increases very gradually in diameter from 12 or 15μ anteriorly to 40 or 50μ at its posterior end. Bursa (figs. 39, 40) comparatively small, not over twice as wide as the maximum thickness of the body when both lobes are spread out. Posterior end of the body truncate, projecting backward between the wings of the bursa, ventrally forming two rounded protuberances separated by a shallow median groove. The paired rays are of nearly equal thickness, except the latero-ventral ray, which is slightly thicker than the others. Measured on the periphery of the bursa, the distance between the anterior end of the bursa and the tips of the ventral rays (*v. v.*, *l. v.*, figs. 39, 40) is about equal to that between the latter and the tip of the externo-dorsal ray (*e. d.*, figs. 39, 40). The tips of the medio-lateral (*m. l.*, figs. 39, 40) and postero-lateral rays, like those of the ventral rays, are very close together. The dorsal ray (*d.*, figs. 39, 40) is about 50 to 60μ in length, bifurcated 35 to 45μ from its root, the two branches being straight and slender, diverging somewhat, and each dividing into two very short branches at the tip. The spicules (fig. 41, *sp.*, fig. 39) measure 220 to 230μ in length. Two slender processes barbed at the tip come off from the inner side of each spicule in its posterior half. When the spicule is retracted, these processes lie close to the body of the spicule, but when the spicule is protruded, their tips spring away from the body of the spicule, one in the dorsal and the other in the ventral direction, giving the end of the spicule in a lateral view a three-forked appearance, the body of the spicule truncated at the distal end forming the thick middle branch, and the barbed processes forming the more slender dorsal and ventral branches of the fork. The gubernaculum is elongated, its body oval, rounded anteriorly, and drawn into a slender process posteriorly. The body of the gubernaculum is about 14μ wide and 40μ long, exclusive of the posterior process, which is about 25μ in length. Prominent short strands of muscle extend between the gubernaculum and the dorsal surface of the body, arranged in two groups side by side. These muscle groups measure about 70μ in length (antero-posteriorly) and 18μ in transverse thickness.

*Female* 8.3 to 9.2 mm. long by 120 to 160μ in thickness in the region of the vulva. The head measures 18 to 20μ in diameter; at the nerve ring the body is 40 to 45μ in thickness, at the base of the esophagus 65 to 85μ, and at the anus 40 to 50μ. The esophagus is similar in size to that of the male, and is surrounded by a nerve ring 260 to 280μ from the anterior end. The vulva (*vul.*, fig. 42) is a transverse slit covered by a prominent cuticular flap (*lab.*, fig. 42), and is situated 1.3 to 1.5 mm. from the posterior end of the body. The tail (fig. 43) tapers gradually and ends in a slender rounded tip. The anus (*an.*, fig. 43) is situated 100 to 140μ from the tip of the tail. The muscular portions of the ovijectors (*ovij. 1–2*, fig. 43) form an elongated barrel-

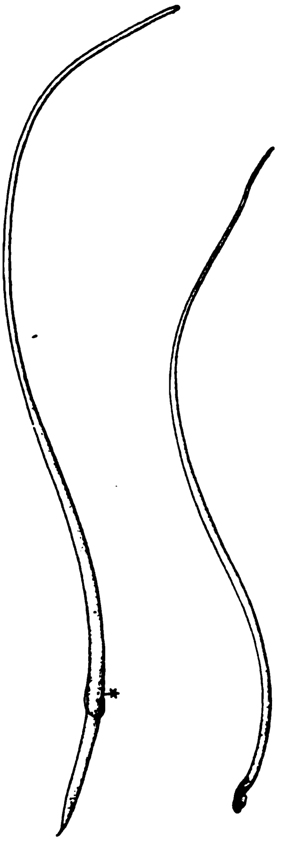


FIG. 38.—*Ostertagia ostertagi*. Male at right, female at left. * Vulva. × 15. (Original.)

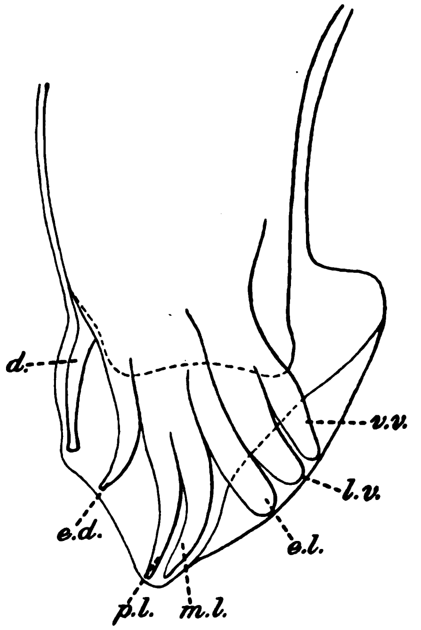


FIG. 40.—*Ostertagia ostertagi*. Bursa of male, viewed from right side. *d.*, dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l .v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *v. v.*, ventro-ventral ray. × 300. (Original.)

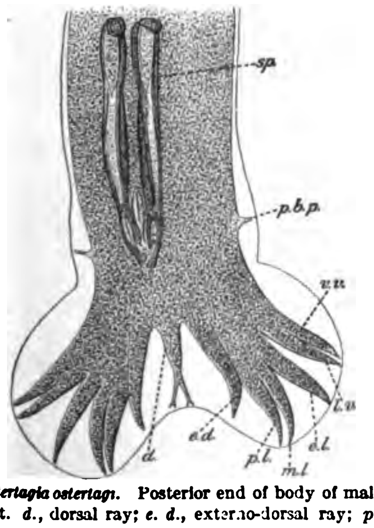


FIG. 39.—*Ostertagia ostertagi*. Posterior end of body of male with bursa spread out. *d.*, dorsal ray; *e. d.*, externo-dorsal ray; *p. l.*, postero-lateral ray; *m. l.*, medio-lateral ray; *e. l.*, externo-lateral ray, *l. v.*, latero-ventral ray; *v. v.*, ventro-ventral ray; *p. b. p.*, pre-bursal papilla; *sp.*, spicules. × 150. (After Railliet, 1893a, fig. 303 )

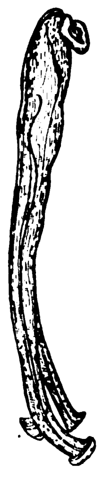


FIG. 41.—*Ostertagia ostertagi*. Spicule of male, lateral view. × 300. (Original.)

shaped structure measuring 200 to 260$\mu$ long, including the sphincters, and 60 to 80$\mu$ in diameter. The eggs measure from 65 by 30$\mu$ to 80 by 40$\mu$ in diameter.

HOSTS.—*Cattle (*Bos taurus*); *bharal (*Ovis nahura*); ?sheep (*Ovis aries*).

LOCATION.—Small nodules in the wall of the fourth stomach and also free in the cavity of the fourth stomach.

LOCALITIES COLLECTED.—Europe, United States, ?Australia, and New Zealand.

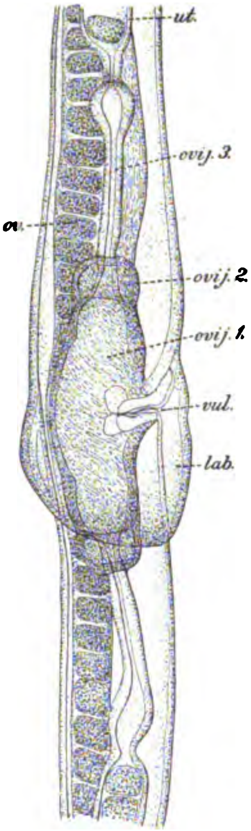


FIG. 42.—*Ostertagia ostertagi.* Body of female in region of vulva, viewed from right side. *lab.*, cuticular flap covering vulva; *ov.*, ovary; *ovij. 1*, terminal portion of ovijector; *ovij. 2*, sphincter of ovijector; *ovij.* 3, nonmuscular portion of ovijector; *ut.*, uterus; *vul.*, vulva. × 150. (Original.)

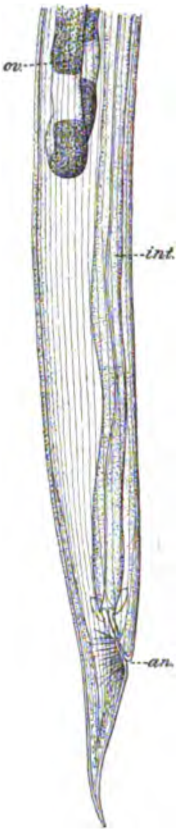


FIG. 43.—*Ostertagia ostertagi.* Posterior end of body of female viewed from right side. *an.*, anus; *int.*, intestine; *ov.*, ovary. × 150. (Original.)

This species has been frequently reported by various authors as a parasite of sheep, but in most instances such reports have evidently resulted from a confusion with *Ostertagia circumcincta.* Among hundreds of specimens of species of *Ostertagia* from domestic sheep, mostly collected in this country, which I have examined, I have failed to find *O. ostertagi.* I have, however, found it once in a blue wild sheep or bharal which died at the National Zoological Park, Washington, D. C.

According to Stadelmann (1891a), the small nodules in which this species is found vary in size from that of a pin head to that of a pea. The presence of *O. ostertagi* in young cattle is commonly associated with an anemic condition of the animals. The parasites not only apparently suck blood, but set up a catarrhal inflammation in spots on the stomach wall, where the nodules are numerous. The development of the parasite is evidently direct, without intermediate host. Following infection, the larvæ penetrate beneath the epithelium of the stomach and there develop to maturity, undergoing two molts in the process of growth.

### **Ostertagia circumcincta** (Stadelmann, 1894) Ransom, 1907.

(Figs. 44–49.)

1893: *Strongylus vicarius* Stadelmann, 1893a, pp. 219–220 (possibly identical with *O. circumcincta*).

1894: *Strongylus circumcinctus* Stadelmann, 1894a, pp. 142–146, figs. 1–2.

1897: *Strongylus cervicornis* McFadyean, 1897c, pp. 48–63, fig. 1, pl. 1, figs. 2–10.

1897: *Strongylus instabilis* Railliet of Julien, 1897e, p. 544, fig. 3a–c (misdetermination).

1907: *Ostertagia circumcincta* (Stadelmann, 1894) Ransom, 1907k, p. 2.

SPECIFIC DIAGNOSIS.—*Ostertagia* (p. 54): Lips or circumoral papillæ indistinct. Head about 18μ in diameter. Cervical papillæ 210 to 350μ from anterior end. Cuticle with about 30 longitudinal ridges. Esophagus 500 to 640μ in length by about 12μ in diameter at the beginning and 40 to 50μ at the posterior end, surrounded by a nerve ring a little in front of the middle. Excretory pore in the neighborhood of the nerve ring.

*Male* 7.5 to 8.5 mm. long by 100 to 130μ in maximum thickness. Bursa (figs. 45, 46) about three times as wide as the maximum thickness of the body when both wings are spread out. The latero-ventral (*l. v.*, figs. 45, 46), externo-lateral (*e. l.*, figs. 45, 46), and medio-lateral (*m. l.*, figs. 45, 46) rays are of about equal thickness, the externo-lateral ray being usually the thickest of the three and all are thicker than the other rays. The tips of the externo-lateral, medio-lateral, postero-lateral (*p. l.*, figs. 45, 46), and externo-dorsal (*e. d.*, figs. 45, 46) rays are separated successively by nearly equal intervals. The dorsal ray (*d.*, fig. 46) has a stem 50 to 60μ long with branches (*t. d.*, fig. 45) about 40μ in length, each with two short side branches, one internally near the tip and the other externally at a greater distance from the tip. Spicules (fig. 47) 280 to 320μ long, divided distally into a slender tapering pointed inner process, and a thicker, slightly longer outer process, slightly curved ventrally near the end and truncated at the tip. Gubernaculum or accessory piece (*gub.*, fig. 47) with lozenge-shaped body rounded at the angles, and slender posterior process; total length about 90μ, of which the posterior process makes up about two-thirds; maximum width about 30μ.

*Female* 9.8 to 12.2 mm. long by 100 to 160μ in maximum thickness in the region of the vulva. Vulva situated 1.9 to 2.3 mm. from the posterior end of the body, transversely elongated, crescentic, may be naked, but is usually covered by a backward projecting flap. Anus (*an.*, fig. 48) 130 to 160μ from the tip of the tail. Diameter of the body at the anus 35 to 55μ. Tail gradually attenuated and rounded at the tip. A short distance in front of the tip the tail is slightly swollen and in this region is marked by 3 to 5 annular striations (fig. 49). Combined length of the muscular por-

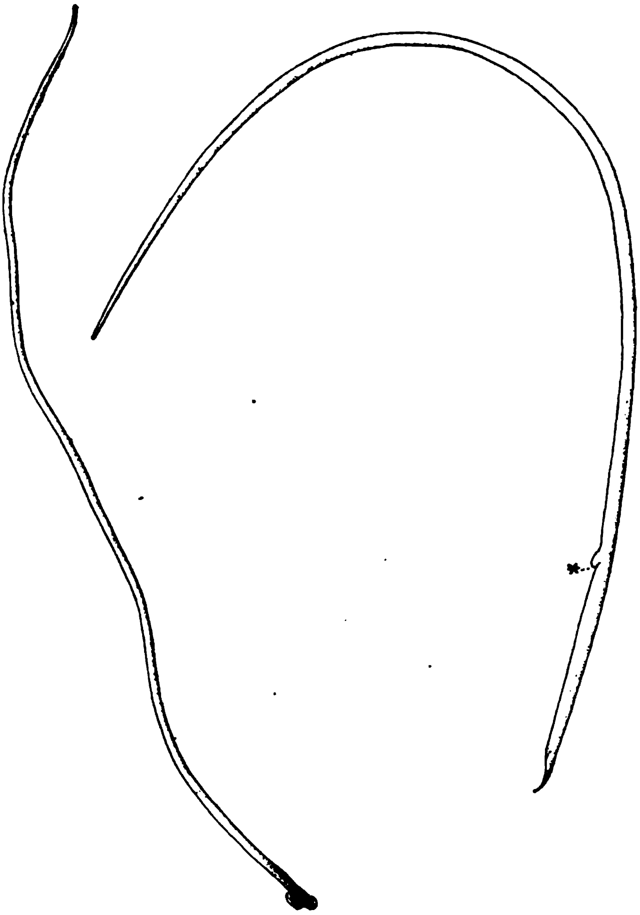


FIG. 44.—*Ostertagia circumcincta*. Male at left, female at right. * Vulva. × 15. (Original.)

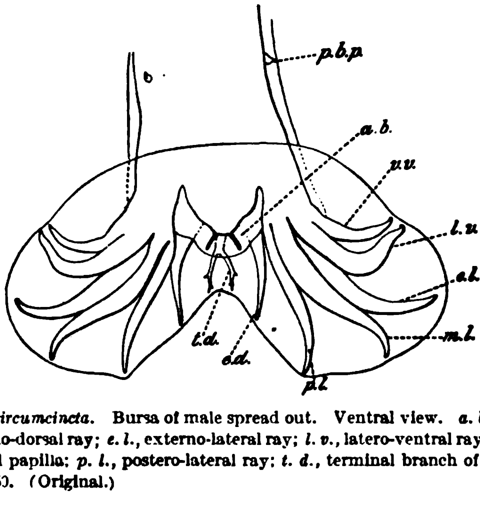


FIG. 45.—*Ostertagia circumcincta*. Bursa of male spread out. Ventral view. *a. b.*, accessory bursal membrane; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. b. p.*, pre-bursal papilla; *p. l.*, postero-lateral ray; *t. d.*, terminal branch of dorsal ray; *v. v.*, ventro-ventral ray. × 150. (Original.)

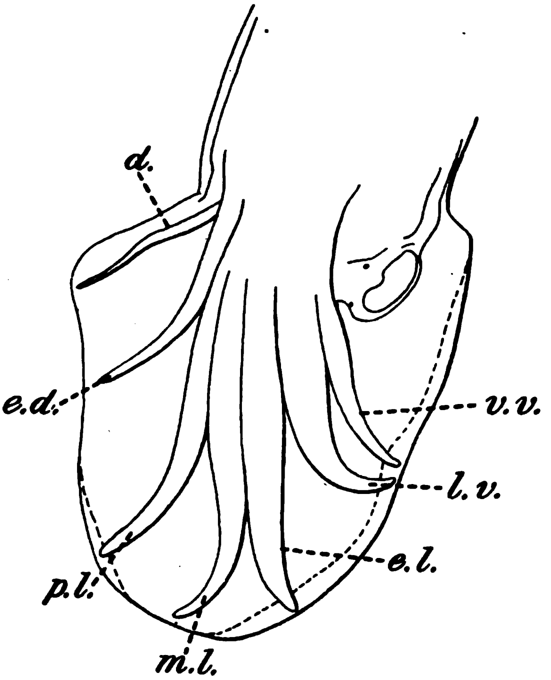


FIG. 46.—*Ostertagia circumcincta.* Bursa of male, viewed from right side. *d.*, dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *v. v.*, ventro-ventral ray. × 300. (Original.)

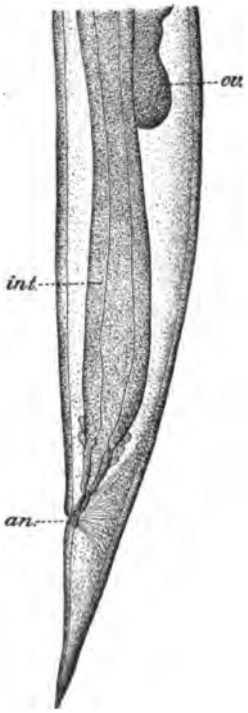


FIG. 48.—*Ostertagia circumcincta.* Posterior end of body of female, viewed from left side. *an.*, anus *int.*; intestine; *ov.*, ovary. × 150. (Original.)

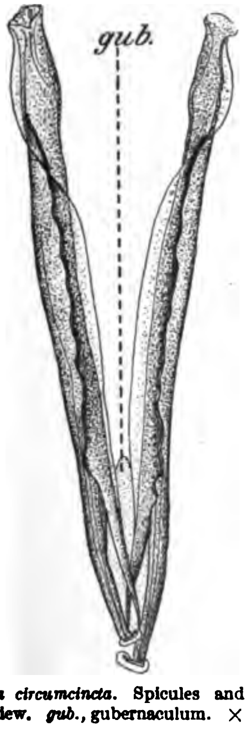


FIG. 47.—*Ostertagia circumcincta.* Spicules and gubernaculum of male. Ventral view. *gub.*, gubernaculum. × 300. (Original.)

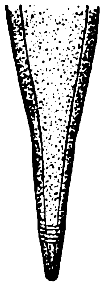


FIG. 49.—*Ostertagia circumcincta.* Tip of tail of female. × 400. (Original.)

tions of the ovijectors including the sphincters 330 to 560μ. Eggs 75 to 100μ long by 35 to 50μ wide.

HOSTS.—*Sheep (*Ovis aries*); *goat (*Capra hircus*); *prong-horned antelope (*Antilocapra americana*); *Newfoundland caribou (*Rangifer terrænovæ*).

LOCATION.—Fourth stomach and small intestine.

LOCALITIES COLLECTED.—Europe, United States, New Zealand, Australia.

The form from the fourth stomach of sheep which Stadelmann (1893a) referred to as *Strongylus vicarius* may possibly be of the same species as his *S. circumcinctus*. The identity of *S. vicarius* will probably, however, always remain doubtful, as type specimens apparently were not preserved, and as it is impossible to determine specimens definitely as *S. vicarius* upon the basis of Stadelmann's description.

### **Ostertagia trifurcata** Ransom, 1907.

(Figs. 50–54.)

1907: *Ostertagia trifurcata* Ransom, 1907k, p. 2.

SPECIFIC DIAGNOSIS.—*Ostertagia* (p. 54): *Male* 6.5 to 7 mm. long by 80 to 100μ in maximum thickness just in front of bursa. Longitudinal ridges of the cuticle frequently exhibit a very finely beaded appearance. Head about 15μ in diameter. Esophagus 460 to 480μ in length by 10μ in diameter anteriorly gradually increasing in thickness posteriorly, and reaching a maximum diameter of about 40μ. Nerve ring about 230μ from the anterior end; cervical papillæ 300μ; and excretory pore 290μ. Bursa (figs. 51, 52) about 300μ in width when both wings are spread out. The latero-ventral (*l. v.*, figs. 51, 52), externo-lateral (*e. l.*, figs. 51, 52), and medio-lateral (*m. l.*, figs. 51, 52), rays are thicker than the other rays and are about equal in thickness, the latero-ventral ray, however, being slightly the thickest. The tips of the externo-dorsal (*e. d.*, figs. 51, 52), postero-lateral (*p. l.*, figs. 51, 52), and medio-lateral rays are separated successively by nearly equal intervals, about twice as great as the interval between the tips of the medio-lateral and externo-lateral rays. The stem of the dorsal ray measures 40 to 50μ in length; its branches (*t. d.*, fig. 51) 35 to 40μ. Each branch near its middle has a short branch on its outer side, and near the tip a short branch on the inner side as in *O. circumcincta*. Spicules (figs. 53, 54) 150 to 180μ long, divided distally into three processes, one long, thick, and truncated at the end, and two considerably shorter, thinner, tapering, and sharply pointed. Gubernaculum (*gub.*, figs. 53, 54) 70 to 90μ long by 10 to 15μ in width anteriorly and drawn out into a slender process posteriorly.

*Female* unknown.

HOSTS.—*Sheep (*Ovis aries*); *goat (*Capra hircus*).

LOCATION.—Fourth stomach, more rarely small intestine.

LOCALITIES COLLECTED.—United States.

TYPE SPECIMENS.—Bureau of Animal Industry Helminthological Collection, No. 4252, collected November 27, 1905, at Bethesda, Md., by Dr. E. C. Stevenson from the fourth stomach of a sheep.

This species has been found several times in small numbers in sheep and goats, always associated with *O. circumcincta*.

### **Ostertagia marshalli** Ransom, 1907.

(Figs. 55–58.)

1904: *Hæmonchus* sp. Marshall, 1904a, p, 182.

1907: *Ostertagia marshalli* Ransom, 1907k, p. 3.

SPECIFIC DIAGNOSIS.—*Ostertagia* (p. 54): *Male* 10 to 13 mm. long by 165 to 200μ in maximum thickness at base of bursa. Head 15 to 20μ in thickness; diameter of body at base of esophagus 70 to 80μ. Cervical papillæ 340 to 415μ from anterior end of body.

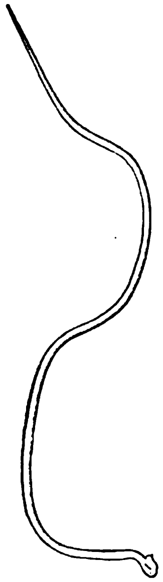


FIG. 50.—*Ostertagia trifurcata*. Male. × 15. (Original.)

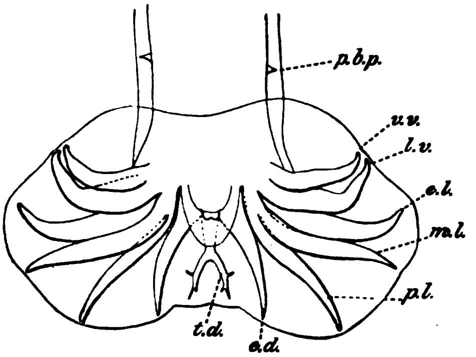


FIG. 51.—*Ostertagia trifurcata*. Posterior end of body of male with bursa spread out. Ventral view. *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. b. p.*, prebursal papilla; *p. l.*, postero-lateral ray; *t. d.*, terminal branch of dorsal ray; *v. v.*, ventro-ventral ray. × 150. (Original.)

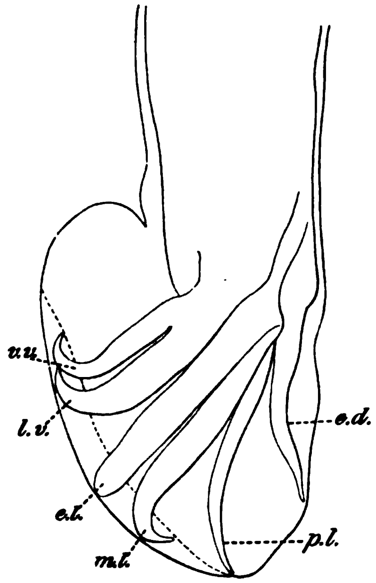


FIG. 52.—*Ostertagia trifurcata*. Posterior end of body of male, viewed from left side. *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *v. v.*, ventro-ventral ray. × 300. (Original.)

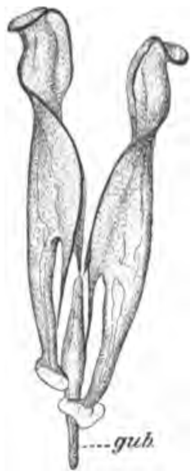


FIG. 53.—*Ostertagia trifurcata*. Spicules and gubernaculum. Ventral view. *gub.*, gubernaculum. × 300. (Original.)

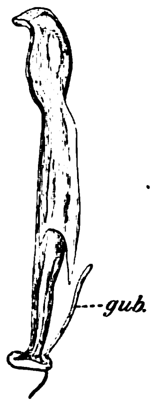


FIG. 54.—*Ostertagia trifurcata*. Spicule and gubernaculum. Lateral view. *gub.*, gubernaculum. × 300. (Original.)

Esophagus 725 to 850$\mu$ long by 10 to 15$\mu$ in diameter anteriorly, increasing to a maximum of 50 to 60$\mu$ at its posterior end, the increase being very slight and gradual until the nerve ring is passed, then there is a sudden increase, then a gradual increase again until the end is reached. Nerve ring at about one-third the length of the esophagus from its anterior end. Bursa (fig. 56) 550 to 690$\mu$ in width when both wings are spread out. Dorsal ray (*d.*, fig. 56) slender, 280 to 400$\mu$ long, bifurcated 200 to 280$\mu$ from its base.

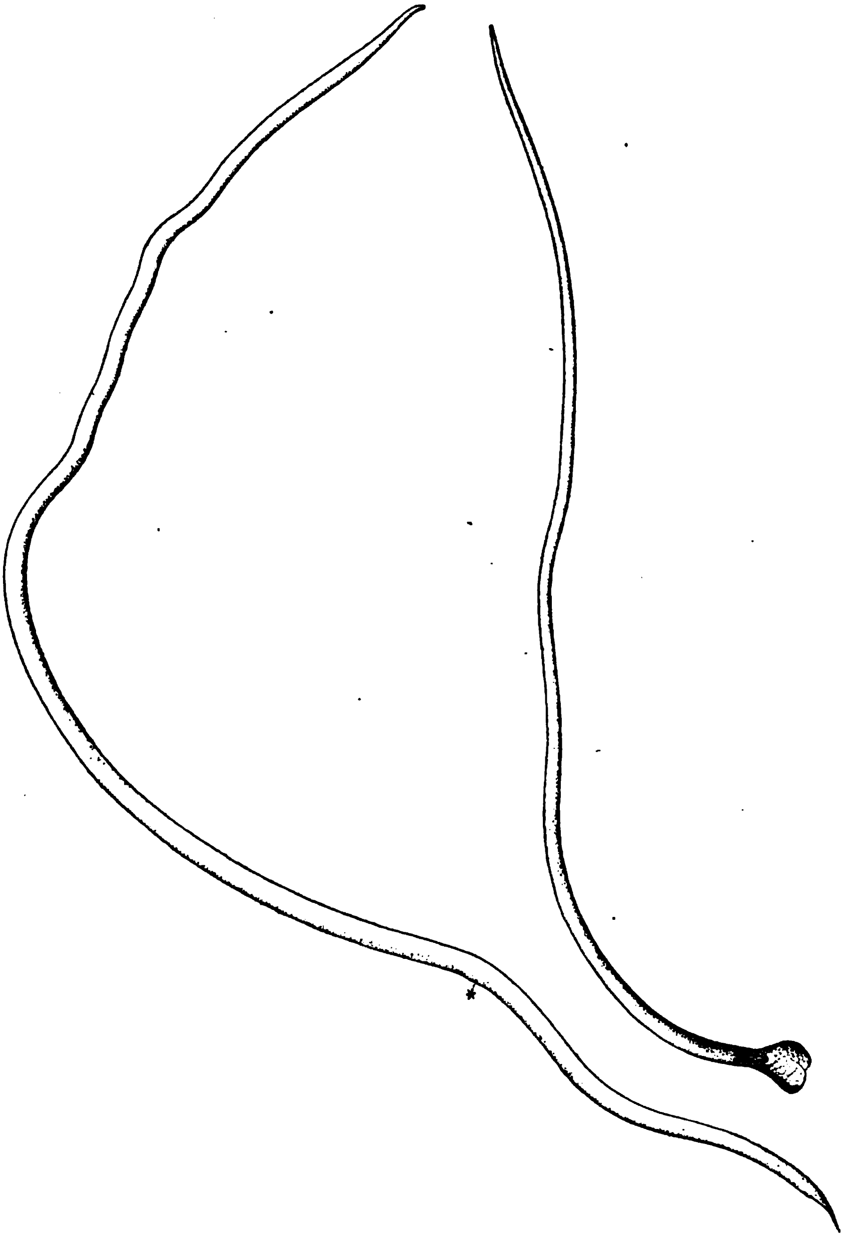


FIG. 55.—*Ostertagia marshalli.* Male at right, female at left. * Vulva. × 15. (Original.)

Each branch is cleft at the end, near which is also a short lateral branch on the outer side. In order of thickness the paired rays rank as follows: Latero-ventral (*l. v.*, fig. 56), externo-lateral (*e. l.*, fig. 56), and medio-lateral (*m. l*, fig. 56) of about the same maximum thickness, then the postero-lateral (*p. l.*, fig. 56), and finally the externo-dorsal (*e. d.*, fig. 56), and ventro-ventral ray (*v. v.*, fig. 56), the last being the shortest as well as usually the most slender. The tips of the externo-dorsal, postero-lateral, and medio-lateral rays are separated successively by nearly equal intervals, about half as great as the interval between the tips of the medio-lateral and externo-lateral rays. The latter interval is about equal to that between the tips of the externo-lateral and latero-ventral rays. The tips of the externo-dorsal, medio-lateral, and externo-lateral rays usually fall a little short of the margin of the bursa. Accessory bursal membrane (*a. b.*, fig. 56) 65 to 75μ long by 70μ wide; its supporting rays about 65μ long. Spicules (fig. 57) 250 to 280μ long, light yellowish-brown in color and rather delicate in structure, split lengthwise in the posterior fourth to form three terminal processes, two ventral and one dorsal. The last is shorter, broader, thinner, and less conspicuous than the other two, both of which are slender. The outer ventral branch is the longest and terminates in an acute point. The end of the inner branch is conical, with a short, blunt, recurved barb. A gubernaculum is absent.

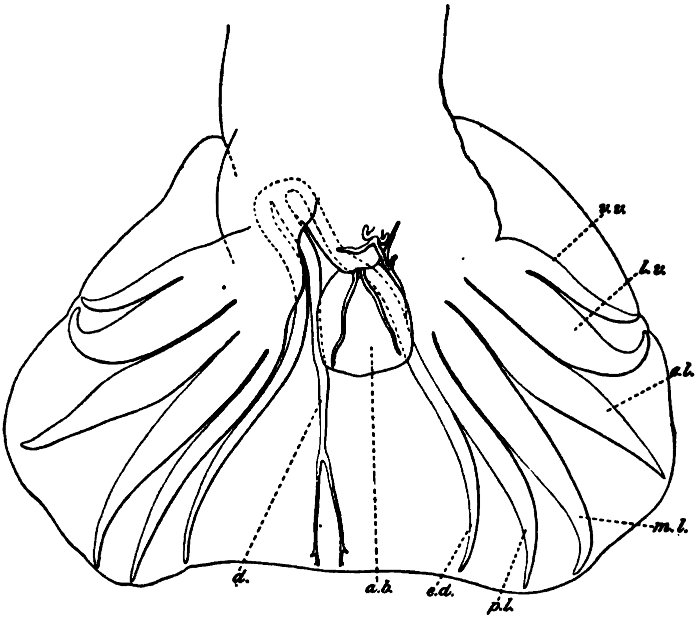


FIG. 56.—*Ostertagia marshalli*. Bursa of male spread out. *a. b.*, accessory bursal membrane; *d.*, dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *v.* r., ventro-ventral ray. × 150. (Original.)

*Female* 12 to 20 mm. long by 200 to 260μ in maximum width in the region of the vulva. Head 15 to 20μ broad; diameter of body at base of esophagus 85 to 100μ, at anus 40 to 60μ. Cervical papillæ 325 to 400μ from anterior end of body. Esophagus 700 to 900μ long, similar in shape and thickness to that of the male. Nerve ring about one-third the length of the esophagus from its anterior end. Anus (*an.*, fig. 58) 200 to 300μ from the tip of the tail. The tail is slender, gradually attenuated and rounded at the tip. The vulva is a transverse slit about 125μ long, situated 2.5 to 5 mm. from the tip of the tail, naked or covered by a backward projecting flap. Combined length of muscular portions of ovijectors, including the sphincters, about 575μ. Eggs large, 160 to 200μ long by 75 to 100μ broad.

HOST.—*Sheep (*Ovis aries*).

LOCATION.—Fourth stomach, more rarely small intestine.

LOCALITY COLLECTED.—Montana.

TYPE SPECIMENS.—Bureau of Animal Industry Helminthological Collection No. 4689, collected February 12, 1907, at Washington, D. C., by Dr. E. C. Stevenson from a sheep received from Montana.

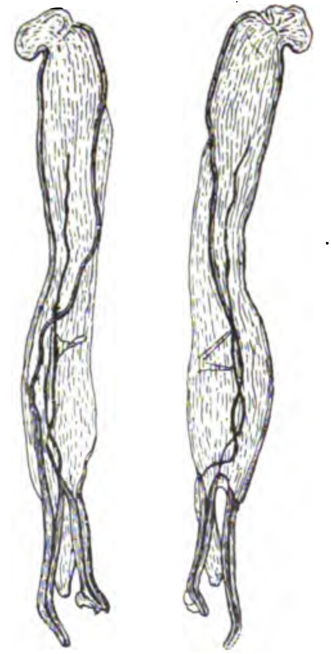


FIG. 57.—*Ostertagia marshalli.* Spicules of male. × 300. (Original.)

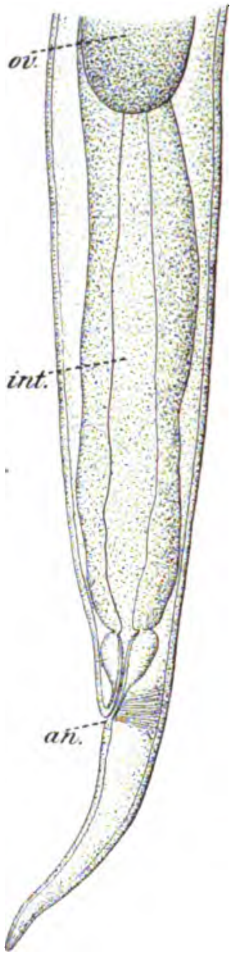


FIG. 58.—*Ostertagia marshalli.* Posterior end of body of female, viewed from left side. *an.*, anus; *int.*, intestine; *ov.*, ovary. × 150. (Original.)

This species was first collected by Dr. H. T. Marshall and Prof. V. K. Chesnut in Montana and has so far been found only in that State or in sheep which have been brought from there. At the present time, therefore, it seems to be confined to the Rocky Mountain region of the United States.

### **Ostertagia occidentalis** Ransom, 1907.

(Figs. 59-61.)

1907: *Ostertagia occidentalis* Ransom, 1907k, p. 3.

SPECIFIC DIAGNOSIS.—*Ostertagia* (p. 54): *Male* 12 to 16 mm. long by 200 to 240μ in maximum thickness at base of bursa. Head 15 to 18μ in diameter; diameter of body at base of esophagus 95 to 100μ Esophagus 820 to 980μ long by 12 to 14μ in diameter anteriorly and 50 to 65μ in diameter at the posterior end. It increases slightly and gradually in diameter until it passes the nerve ring, and there undergoes a sudden increase, after which it again increases gradually toward the posterior end. Nerve ring 280 to 300μ and cervical papillæ 350 to 400μ from the anterior end of the body. Bursa (fig. 60) 650 to 740μ wide when spread out. Dorsal ray (*d.*, fig. 60), 280 to 300μ long, bifurcated at a distance of about 200μ from its origin. Each branch is cleft at its extremity and bears a short lateral branch on its outer side near the end. In order of thickness the paired rays usually rank as follows: Thickest, externo-lateral (*e. l.*, fig. 60), then latero-ventral (*l. v.*, fig. 60), and medio-lateral (*m. l.*, fig. 60), of very nearly the same size, then postero-lateral (*p. l.*, fig. 60), externo-dorsal (*e. d.*, fig. 60), and ventro-ventral (*v. v.*, fig. 60). The tip of the externo-lateral ray is almost equidistant between the tips of the latero-ventral and medio-lateral rays, the intervals between these three being more than twice as great as the nearly equal intervals which separate successively the tips of the externo-dorsal, postero-lateral, and medio-lateral rays. The tips of the externo-dorsal and externo-lateral rays fall some distance short of the margin of the bursa. The accessory bursal membrane (*a. b.*, fig. 60) is about 60μ long by 50μ wide, with supporting rays about 40μ long. The spicules (fig. 61), 290 to 320μ long, are strongly built, dark yellowish-brown in color, and very prominent in appearance. They are divided lengthwise, beginning a short distance posterior of the middle, into three terminal processes, two ventral and one dorsal. The outer ventral process is the longest of the three, obliquely truncated at the end, the inner process the shortest and slenderest, terminating in a short mucronate point. The dorsal process is intermediate in length and is the thickest of the three, being slightly thicker than the outer process. It terminates in a rounded conical tip set off from the rest of the process by a transverse ridge on the dorsal side. Gubernaculum (*gub.*, fig. 61), about 120μ long by 15 to 20μ wide anteriorly, more slender posteriorly, very inconspicuous.

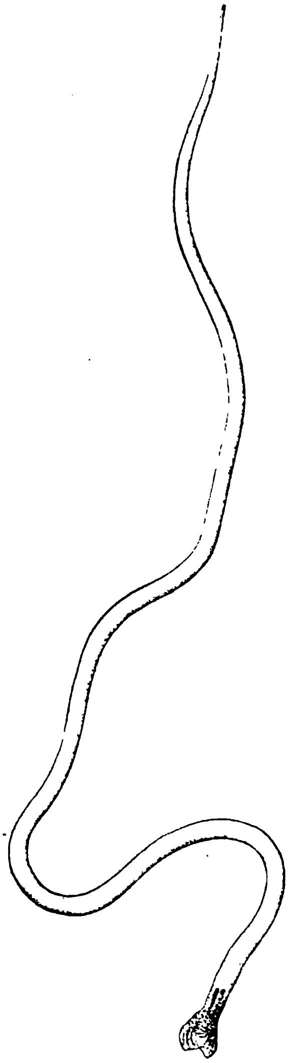


FIG. 59.—*Ostertagia occidentalis*. Male. × 15. (Original.)

*Female* unknown.

HOST.—*Sheep (*Ovis aries*).

LOCATION.—Fourth stomach, more rarely small intestine.

LOCALITY COLLECTED.—Montana.

TYPE SPECIMENS.—Bureau of Animal Industry Helminthological Collection No. 4691, collected February 12, 1907, at Washington, D. C., by Dr. E. C. Stevenson, from a sheep received from Montana.

This species, like *Ostertagia marshalli*, appears to be confined to the Rocky Mountain region. It has been collected several times from Montana sheep, always associated with *O. marshalli*.

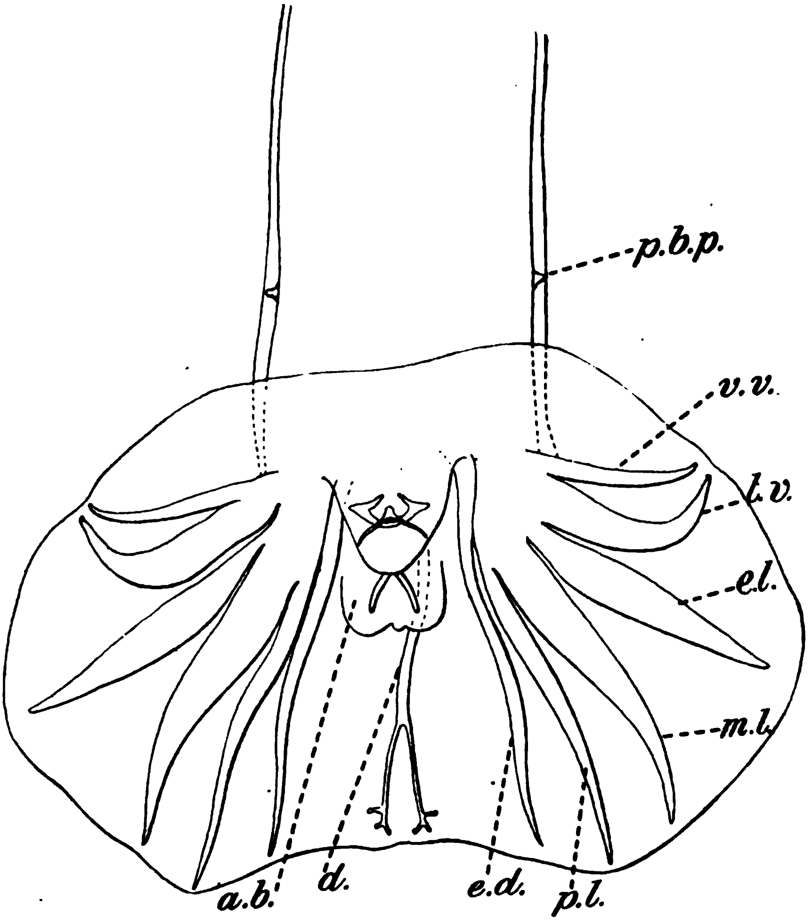


FIG. 60.—*Ostertagia occidentalis*. Posterior end of body of male, with bursa spread out. Ventral view. *a. b.*, accessory bursal membrane; *d.*, dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. b. p.*, pre-bursal papilla; *p. l.*, postero-lateral ray; *v. v.*, ventro-ventral ray. × 150. (Original.)

### **Ostertagia mentulata** Railliet and Henry, 1909.

(Figs. 62–63.)

1909: *Ostertagia mentulata* Railliet and Henry, 1909a, p. 87 (from *Camelus dromedarius*, India).

SPECIFIC DIAGNOSIS.—*Ostertagia* (p. 54): Cuticle marked with about 30 longitudinal lines. Cervical papillæ 350μ (in female) to 450μ (in male) from the anterior end. Esophagus 750μ (in female) to 1 mm. (in male) in length.

*Male* 6.5 to 7.5 long. Membranous wings present along the lateral lines in the posterior portion of the body. Spicules long (700μ), with pincer-like termination 90μ long. One of the branches of the pincer is a little longer than the other, ending in a hammer-shaped hook.

*Female* 8 to 10 mm. long. Vulva in the posterior fifth of the body. Tail bluntly pointed.

HOST.—*Arabian camel (*Camelus dromedarius*).

LOCATION.—Fourth stomach.

LOCALITIES COLLECTED.—India, United States.

The foregoing diagnosis is taken from the brief description given by Railliet and Henry (1909a). The Bureau of Animal Industy collection contains specimens apparently belonging to this species collected from the stomach of a dromedary which died at the National Zoological Park, Washington, D. C. The accompanying drawings were made from these specimens.

**Ostertagia brigantiaca** Blanchard, 1909.

1909: *Ostertagia brigantiaca* Blanchard in Railliet and Henry, 1909a, p. 87 (from Chamois, France).

SPECIFIC DIAGNOSIS.—*Ostertagia* (p. 54): Male 4.25 to 5 mm. long, Spicules 210μ long. Bursa unilobed. with posterior ray as long as the bursa. Trunk of the posterior ray five times the length of its branches.

*Female* 6 to 7 mm. long.

HOST.—Chamois (*Rupicapra rupicapra*).

LOCATION.—Duodenum.

LOCALITY COLLECTED.—France.

The foregoing description is taken from the brief description given by Railliet and Henry (1909a).

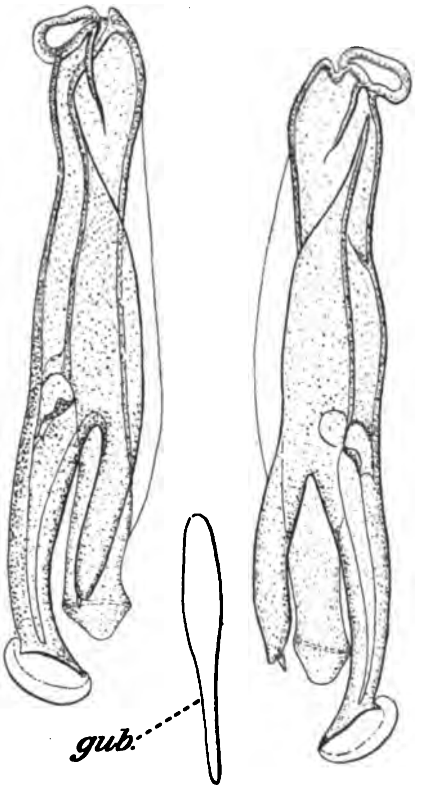


FIG. 61.—*Ostertagia occidentalis*. Spicules and gubernaculum of male. Ventral view. *gub.*, gubernaculum. × 300. (Original.)

## Genus COOPERIA Ransom, 1907.

1907: *Cooperia* Ransom, 1907k, pp. 3–4.

GENERIC DIAGNOSIS.—Metastrongylinæ (p. 47): Head rounded, relatively thick, 25μ or more in diameter, without well marked lips or papillæ. Cuticle of head region transversely striated, and often dilated, giving the head a swollen or bulbous appearance. Cuticle of remainder of body with 14 to 16 longitudinal lines or ridges. From a surface view each longitudinal line or ridge appears to be made up of a row of small punctations standing close together, which resemble striations perpendicular to the surface of the body when the longitudinal line or ridge is viewed from the side. Cervical papillæ absent. Mouth cavity small, indefinite. Bursa of male with two lateral lobes and a small median lobe. Ventro-ventral ray short and slender, curving forward. Distal portion of latero-ventral ray curves forward, while the distal portion of the externo-lateral ray turns backward so that the tips of these two rays are far apart. The other lateral rays and the externo-dorsal ray also turn backward and their tips are near the posterior border of the bursa, separated by short intervals. The unpaired dorsal ray is divided into two prominent branches which may be parallel or curved so as to form together a lyre-shaped or horseshoe-shaped structure. Each branch may or not be cleft at the end. From each main branch, usually near its junction with the stem of the dorsal ray, a short branch extends ventrally into a vesicular swelling on the inner surface of the bursa. Spicules short. Gubernaculum or accessory piece absent. Prebursal papillæ absent. Vulva in the posterior fourth of the body, elongated transversely or longitudinally. Ovijectors well developed. Eggs oval with thin shells measuring 60 to 80$\mu$ in length.

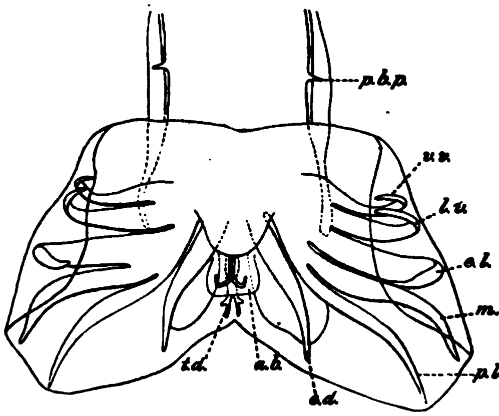


FIG. 62.—*Ostertagia mentulata*. Posterior end of body of male, with bursa partially spread out. Ventral view. *a. b.*, accessory bursal membrane; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. b. p.*, pre-bursal papilla; *p. l.*, postero-lateral ray; *t. d.*, terminal branch of dorsal ray; *v. v.*, ventro-ventral ray. × 150. (Original.)

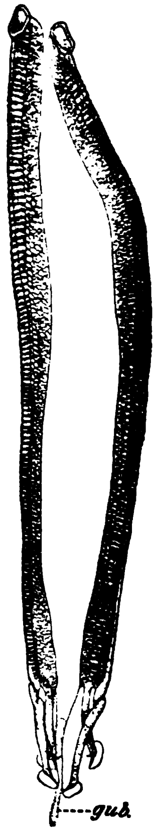


FIG. 63.—*Ostertagia mentulata*. Spicules and gubernaculum of male. Ventral view. *gub.*, gubernaculum. × 300. (Original.)

TYPE SPECIES.—*Cooperia curticei* (Railliet, 1893) Railliet and Henry, 1909.

Four species of *Cooperia* occur in ruminants, and all of these have been found in America.

### KEY TO SPECIES OF COOPERIA.

1. Spicules of male less than 200$\mu$ in length ......... 2
   Spicules more than 200$\mu$ in length ................. 3
2. Branches of the dorsal ray of bursa curved to form a lyre-shaped structure; spicules 135 to 145$\mu$ long; vulva of female a transverse slit; male 4.6 to 5.4 mm. long, female 5.8 to 6.2 mm. long.. *Cooperia curticei*, p. 71
   Branches of the dorsal ray of bursa nearly straight, almost parallel; spicules 120 to 150$\mu$ long; vulva of female crescentic in shape, elongated longitudinally; male 4.7 to 5.9 mm. long, female 5.7 to 7.5 mm. long... *Cooperia punctata*, p. 74

3. Main branches of the dorsal ray of the bursa rather widely divergent, forming a U-shaped arch with cleft tips; spicules 240 to 300μ long, gradually reduced in size posteriorly; terminal portion of tail of female marked with annular striations; body much swollen in region of vulva; combined length of muscular portions of ovijectors about 700μ; male 5.5 to 9 mm. long, female 6 to 8 mm. long. *Cooperia oncophora*, p. 77

Main branches of the dorsal ray of the bursa rather close together, parallel, with uncleft tips; spicules 240 to 300μ long with a prominently projecting corrugated edge in the middle third; terminal portion of very sharply pointed tail of female not marked with annular striations; combined length of muscular portions of ovijectors about 300μ; male about 7 mm. long, female 7.5 to 9 mm. long.........*Cooperia pectinata*, p. 81

### **Cooperia curticei** (Railliet, 1893) Railliet and Henry, 1909.

(Figs. 64–71.)

1890: *Strongylus ventricosus* Rudolphi of Curtice, 1890c, pp. 149–150, pl. 20, figs. 1-9 (in part).

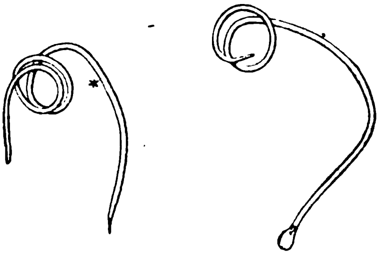


FIG. 64.—*Cooperia curticei.* Male at right, female at left. *Vulva. × 15. (Original.)

1892: *Strongylus curticii* Giles, 1892d, p. 49 (=*S. ventricosus* Rud. of Curtice, 1890, renamed).

1893: *Strongylus curticei* Railliet, 1893a, p. 442 (emendation of *S. curticii*).

1907: *Cooperia curticii* (Giles) Ransom, 1907k, pp. 3–4.

1909: *Cooperia curticei* (Railliet) Railliet and Henry, 1909a, p. 87.

SPECIFIC DIAGNOSIS.—*Cooperia* (p. 69): Anterior end of body usually coiled spirally (fig. 64). Head 28 to 50μ in diameter, varying according to the degree of expansion of the cuticle. Esophagus 250 to 275μ long in the male and 255 to 290μ long in the female; diameter at the anterior end about 20μ, soon decreasing to about 15μ, and then gradually increasing to about 30 to 35μ at its posterior end. Nerve ring situated near the beginning of the posterior fourth of the esophagus. Excretory pore opening on the ventral surface of the body 10 to 20μ behind the posterior end of the esophagus.

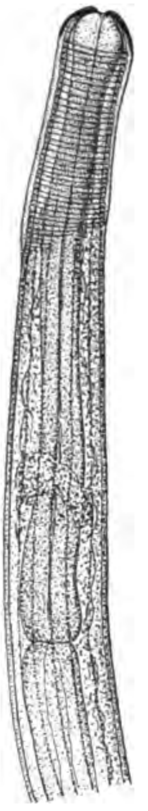


FIG. 65.—*Cooperia curticei.* Anterior end of body. Lateral view. × 300. (Original.)

*Male* 4.6 to 5.4 mm. long by 75 to 80μ in maximum diameter. Bursa (figs. 66, 67) about 300μ wide when both wings are spread out. The tips of all of the paired rays are very close to the edge of the bursa. The ventro-ventral ray (*v. v.*, figs. 66, 67) is the shortest and most slender of the paired rays. Next in order of thickness is the externo-dorsal (*e. d.*, figs. 66, 67), then the postero-lateral (*p. l.*, figs. 66, 67), medio-lateral (*m. l.*, figs. 66, 67), externo-lateral (*e. l.*, figs. 66, 67), and finally the thickest is the latero-ventral ray (*l. v.*, figs. 66, 67). The externo-lateral is almost but not quite equal in thickness to the latero-ventral ray. The stem of the dorsal ray (*d.*, fig. 66) and its branches are each about 35μ long. The latter (*t. d.*, figs. 66, 67) are curved so as to form a lyre-shaped structure, each is cleft at the end, and gives off a

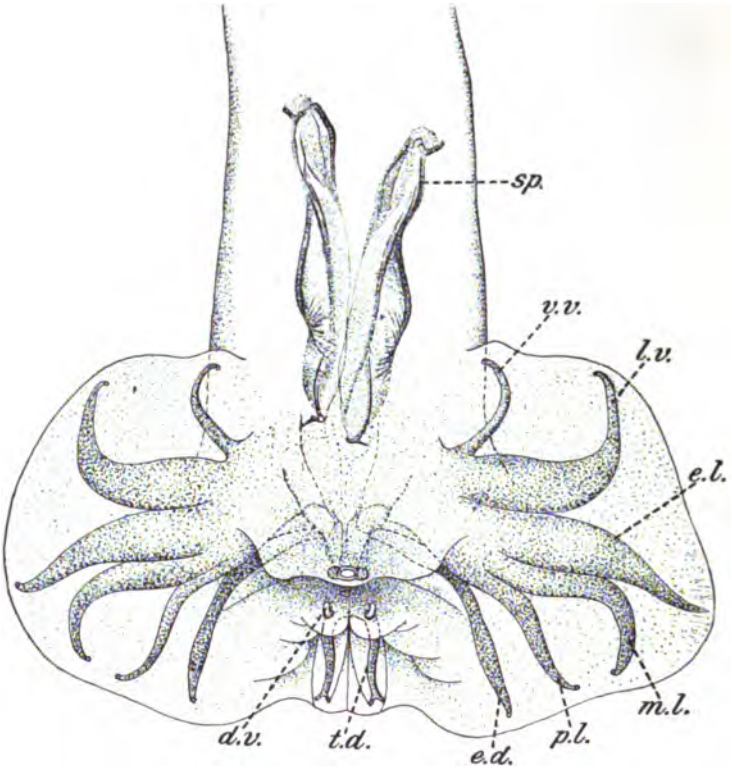


FIG 66.—*Cooperia curticei.* Posterior end of body of male with bursa spread out. Ventral view. *d. v.*, ventral branch of dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *sp.*, spicule; *t. d.*, terminal branch of dorsal ray; *v. v.*, ventro-ventral ray. × 300. (Original.)

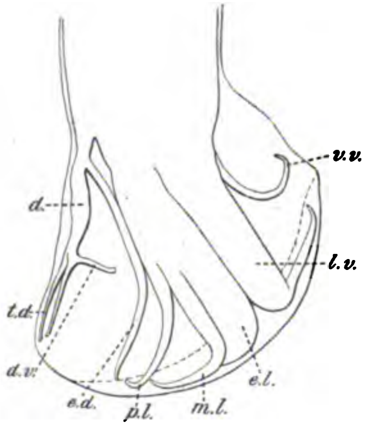


FIG. 67.—*Cooperia curticei.* Bursa of male, viewed from right side. *d.*, dorsal ray; *d. v.*, ventral branch of dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *t. d.*, terminal branch of dorsal ray; *v. v.*, ventro-ventral ray. × 300. (Original.)

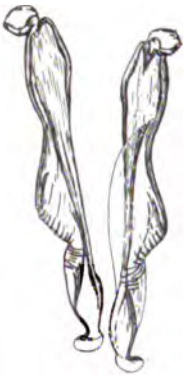


FIG. 68.—*Cooperia curticei.* Spicules of male. Ventral view. × 300. (Original.)

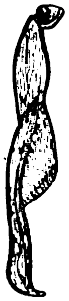


FIG. 69.—*Cooperia curticei.* Spicule of male. Lateral view. × 300. (Original.)

ventral branch (*d. v.*, figs. 66, 67) at its origin. Spicules (figs. 68. 69; *sp.*, fig. 66) 135 to 145$\mu$ long. In the middle region of the spicule the ventral edge forms a thin prominent projection marked on the inner surface with corrugations at right angles to the border.

*Female* 5.8 to 6.2 mm. long by 75 to 100$\mu$ in maximum thickness. Vulva (*vul.*, fig. 70) a transverse slit about 80$\mu$ in length, surrounded by chitinous lips, and situated 1.25 to 1.4 mm. from the posterior end of the body. Tail (fig. 71) slender, acutely pointed, 110 to 160$\mu$ in length. Combined length of muscular portions of ovijectors (*ovij. 1–2*, fig. 70) including the sphincters 375 to 560$\mu$. The eggs (*e.*, fig. 70) are in the morula stage when laid, measuring 63 to 70$\mu$ in length by 30 to 32$\mu$ in width.

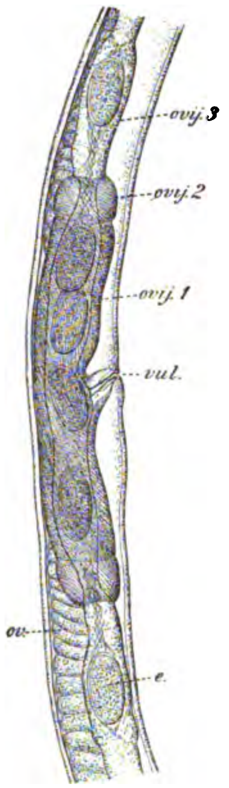


FIG. 70.—*Cooperia curticei.* Body of female in region of vulva viewed from right side. *e.*, egg; *ov.*, ovary; *ovij. 1*, terminal portion of ovijector; *ovij. 2*, sphincter of ovijector; *ovij. 3*, non-muscular portion of ovijector; *vul.*, vulva. × 150. (Original).

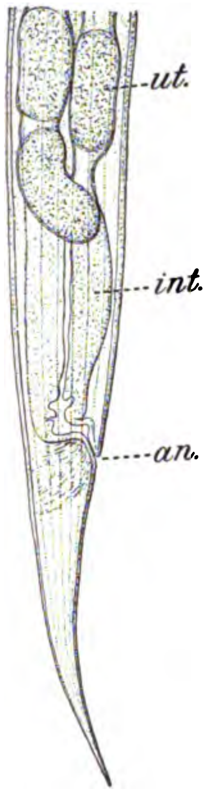


FIG. 71.—*Cooperia curticei.* Posterior end of body of female, viewed from right side. *an.*, anus; *int.*, intestine; *ut.*, uterus. × 300. (Original.)

HOSTS.—*Sheep (*Ovis aries*); *goat (*Capra hircus*).

LOCATION.—Small intestine, more rarely fourth stomach.

LOCALITIES COLLECTED.—United States and (?) Europe.

*Cooperia curticei* was originally described by Curtice (1890c) under the name of *Strongylus ventricosus* Rud. Giles (1892d), recognizing certain differences between Curtice's species from sheep and Rudolphi's species from *Cervus elaphus*, renamed the former, *Strongylus curticii*, a name which was corrected to *S. curticei* by Railliet (1893a).

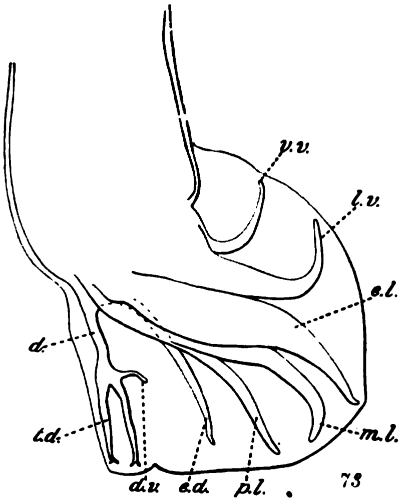
Curtice's description is evidently based on more than one species, as he has shown in his figure 2 a female which is distinctly different from the form shown in his figure 7. The latter, he says, is more characteristic of the species than that of figure 2, but is not quite mature. The fact that he figures eggs in the uterus in figure 7, however, indicates the maturity of the worm from which the drawing was made. I have always found associated with males corresponding to Curtice's figures 1, 8, and 9, mature females corresponding to Curtice's figure 7, and agreeing perfectly with the males as to the head and the markings of the skin, so that there is but little question as to their belonging to the same species. In these females the size of the eggs (63 to 70$\mu$ by 30 to 32$\mu$) is much smaller than that given by Curtice (0.13 mm. long by 0.07 mm. wide), who possibly took his measurements from females corresponding to his figure 2. There is a discrepancy between his description of the length of the spicules and the length as indicated in his figure 1. He gives 0.36 mm. as the size of the spicules, but in the figure of a male drawn to a magnification of about 27 times (as may be determined by comparing the length of the line on the plate indicating the natural size of the worm with the length of the magnified worm) the spicules are shown as a little less than 4.5 mm. in length, which divided by 27 gives an actual length of not over 165$\mu$. This is fairly close to the length 135 to 145$\mu$ found in specimens which I consider unquestionably of the same species as that figured by Curtice. A further apparent error in Curtice's description and figures is that of showing the ventro-ventral ray of the bursa split lengthwise, a condition not found in any specimens examined by me. I have also failed to find any appearance of transverse striation of the cuticle except in the head region, while Curtice's description indicates that the body is transversely striate throughout. Taking everything into consideration, however, there can be no reasonable doubt that the form which I have described above is the true *Strongylus curticei*.

The form from European cattle which Schnyder (1906b, pl. 2, fig. 5) figures as *Strongylus curticei* Giles, and specimens of which I have had the priviledge of examining through the courtesy of Doctor Schnyder, is not that species but evidently *Cooperia oncophora*.

### **Cooperia punctata** (Linstow, 1907) Ransom, 1907.

(Figs. 72-77.)

1906: *Strongylus* sp. Schnyder, 1906b, pp. 182, 183, 186, 193, 194, 195, 196, 199, 204, 245, 249, 264, pl. 1, figs. 2-3.
1907: *Strongylus punctatus* Linstow in Schnyder, 1907d, pp. 708–709.
1907: *Cooperia punctata* (Schnyder, 1907) Ransom, 1907k, p. 3.
1907: *Strongyloides bovis* Vrijburg, 1907k, pp. 321–327, pls. 1-2 (at least in part).



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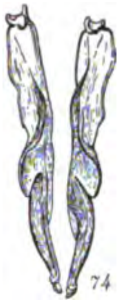

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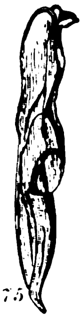

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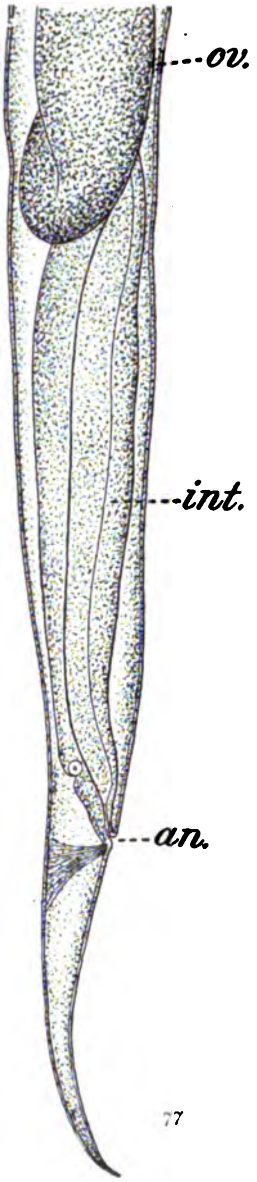

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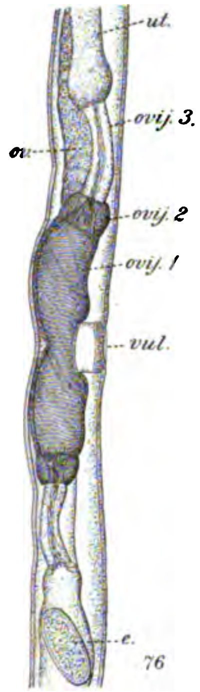

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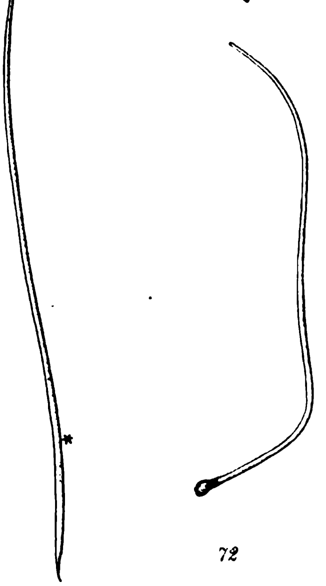

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FIG. 72.—*Cooperia punctata*. Male at right, female at left. * Vulva. × 15. (Original.)

FIG. 73.—*Cooperia punctata*. Bursa of male, viewed from right side. *d.*, dorsal ray; *d. v.*, ventral branch of dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *t. d.*, terminal branch of dorsal ray; *v. v.*, ventro-ventral ray. × 300 (Original.)

FIG. 74.—*Cooperia punctata*. Spicules of male. Ventral view. × 300. (Original.)

FIG. 75.—*Cooperia punctata*. Spicule of male. Lateral view. × 300. (Original.)

FIG. 76.—*Cooperia punctata*. Body of female in region of vulva, viewed from right side. *e.*, egg; *ov.*, ovary; *ovij. 1*, terminal portion of ovijector; *ovij. 2*, sphincter of ovijector; *ovij. 3*, nonmuscular portion of ovijector; *ut.*, uterus; *vul.*, vulva. × 150. (Original.)

FIG. 77.—*Cooperia punctata*. Posterior end of body of female, viewed from right side. *an.*, anus; *int.* intestine; *ov.*, ovary. × 300. (Original.)

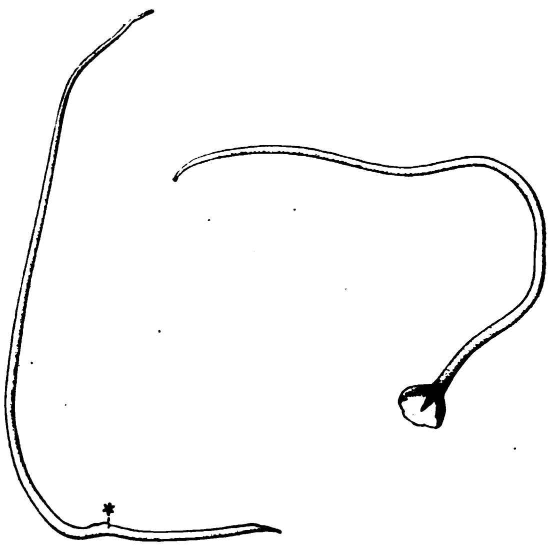


FIG. 78.—*Cooperia oncophora.* Male at right, female at left. *Vulva. × 15. (Original.)

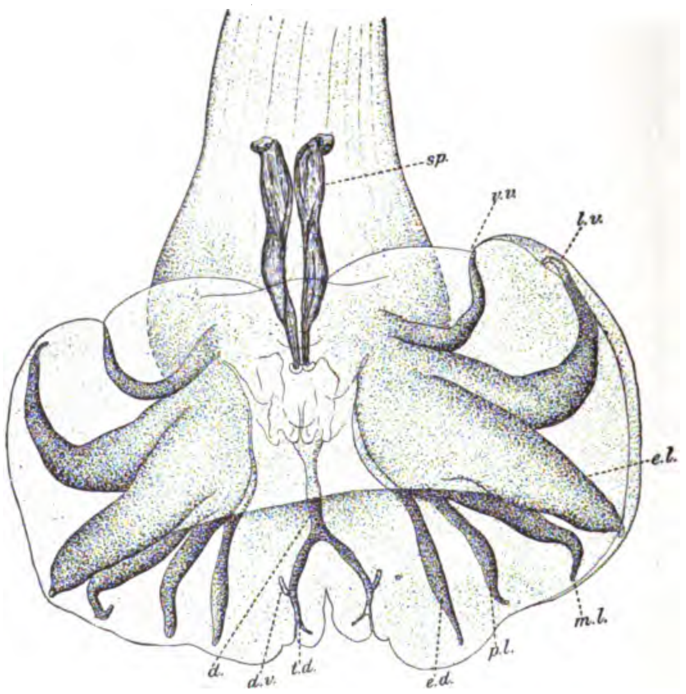


FIG. 79.—*Cooperia oncophora.* **Posterior end of body of male, with bursa spread out. Ventral view.** ***d.*****,** dorsal ray; *d. v.*, ventral branch of dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; ***l. v.*****,** latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; ***sp.*****, spicule;** ***t. d.*****, terminal branch of dorsal ray;** *v. v.*, ventro-ventral ray. × 100. (Original.)

Specific diagnosis.—*Cooperia* (p. 69): Head 30 to 55μ in diameter, varying according to the degree of expansion of the cuticle. Esophagus 255 to 360μ in length in the male and 300 to 340μ in length in the female, surrounded by a nerve ring at a distance of about three-fourths of its length from the anterior end. The esophagus is about 20μ in diameter at its beginning, is then reduced in size for a short distance, after which it gradually increases to a maximum of 30 to 35μ at its posterior end.

*Male* 4.7 to 5.9 mm. long by 70 to 100μ in maximum diameter at the base of the bursa. The latero-ventral ray (*l. v.*, fig. 73) is considerably more slender than the externo-lateral ray (*e. l.*, fig. 73), which is the thickest of all the rays. The latero-ventral ray (*l. v.*, fig. 73) comes next in thickness, then the medio-lateral (*m. l.*, fig. 73), postero-lateral (*p. l.*, fig. 73), externo-dorsal (*e. d.*, fig. 73), and finally the ventro-ventral ray (*v. v.*, fig. 73), which is the most slender of the paired rays. The tips of the rays are close to the edge of the bursa except that of the externo-dorsal ray, which is some distance from the edge, the externo-dorsal ray being proportionately shorter in this species than in *C. curticei*. Of the paired rays the tips of the medio-lateral and postero-lateral rays are the most closely approximated to each other. The stem of the dorsal ray (*d.*, fig. 73) and its branches are about equal in length to those of *C. curticei*, the stem, however, being somewhat longer, about 40μ in length, with branches 30 to 35μ in length. As in *C. curticei* the branches (*t. d.*, fig. 73) are usually cleft at the end, and each gives off a ventral branch (*d. v.*, fig. 73) at its origin, but they differ from those in the other species in being nearly straight and almost parallel instead of forming a lyre-shaped structure. The spicules (figs. 74, 75) measure 120 to 150μ in length, are without corrugated markings, but exhibit near the middle on the ventral side a deep concavity.

*Female* 5.7 to 7.5 mm. long by 65 to 75μ in maximum diameter in the region of the vulva. The vulva (*vul.*, fig. 76) has prominent chitinous lips, is crescentic in shape, elongated longitudinally, measures 40 to 50μ in length, and is situated 1 to 1.5 mm. from the posterior end of the body. The tail (fig. 77) is slender, tapering, acutely pointed, slightly concave ventrally, very similar in shape to that of *C. curticei*. The anus (*an.*, fig. 77) is located 135 to 160μ from the tip of the tail. Combined length of muscular portions of ovijectors (*ovij. 1–2*, fig. 76), including the sphincters, 250 to 275μ. The eggs (*e.*, fig. 76) measure 65 to 72μ in length by 30μ in width.

Host.—*Cattle (*Bos taurus*).

Location.—Small intestine and fourth stomach.

Localities collected.—Europe, United States, Sumatra.

Comparison of European specimens (B. A. I. Coll. Nos. 15726, 15729, 15732, 15733, presented by Dr. O. Schnyder) with specimens from American cattle has demonstrated the identity of the European and American forms.

The form from cattle in Sumatra described by Vrijburg (1907k, pp. 321–327, pls. 1–2) and named by him *Strongyloides bovis*, is very clearly not a *Strongyloides*. His description and figures indicate that he was dealing with *Cooperia punctata*, in part at least.

### **Cooperia oncophora** (Railliet, 1898) Ransom, 1907.

(Figs. 78–82.)

1803: *Strongylus radiatus* Rudolphi, 1803a, pp. 13–15 (in part; see Schneider, 1866a, p. 139).

1866: *Strongylus ventricosus* Rudolphi of Schneider, 1866a, pp. 129, 131, 132, 139, 144 (in part).

1898: *Strongylus oncophorus* Railliet, 1898b, p. 173 (*S. ventricosus* Rudolphi of Schneider, 1866, renamed).

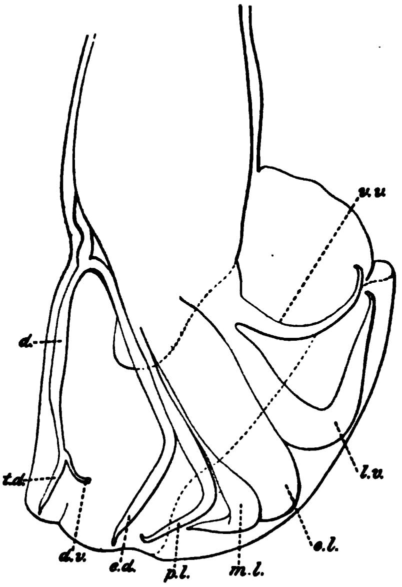


FIG. 80.—*Cooperia oncophora.* Bursa of male, viewed from right side. *d.*, dorsal ray; *d. v.*, ventral branch of dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *t. d.*, terminal branch of dorsal ray; *v. v.*, ventro-ventral ray. × 100. (Original.)

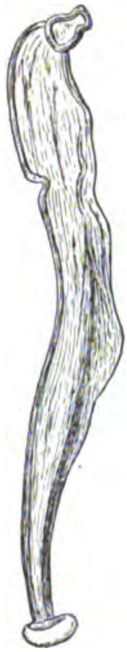


FIG. 81.—*Cooperia oncophora.* Spicule of male. Lateral view. × 300. (Original.)

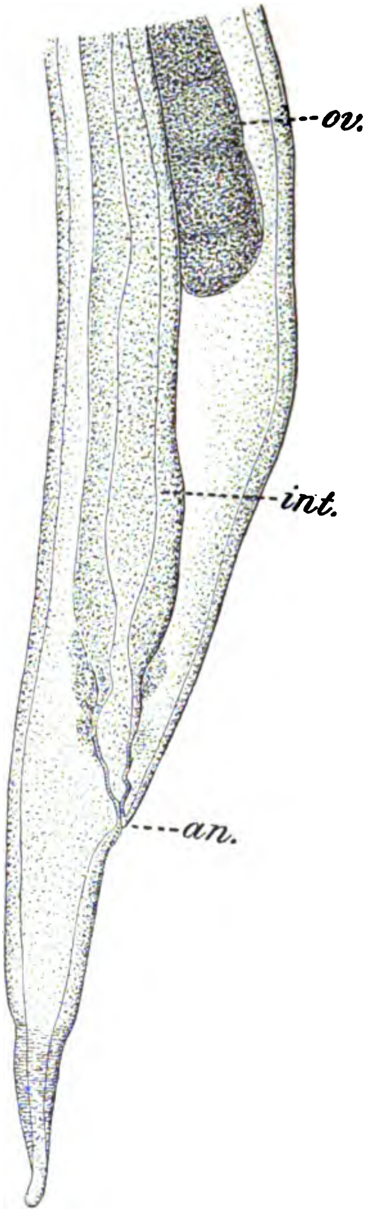


FIG. 82.—*Cooperia oncophora.* Posterior end of body of female, viewed from right side. *an.*, anus; *int.* intestine; *ov.*, ovary. × 300. (Original.)

1906: *Strongylus curticei* Giles of Schnyder, 1906b, pp. 169, 181, 182, 183, 190, 191, 192, 193, 194, 199, 204, 205, 207, 245, 246, 247, 249, 251, 256, 258, 259, 264, pl. 2, fig. 5 (misdetermination).

1907: *Cooperia oncophora* (Railliet, 1898) Ransom, 1907k, pp. 3-4.

SPECIFIC DIAGNOSIS.—*Cooperia* (p. 69): *Male* 5.5 to 9 mm. long by 150 to 250μ wide at the base of the bursa, in which region the thickness of the body undergoes a considerable and rather sudden increase. Head 25 to 40μ in diameter, varying according to the degree of expansion of the cuticle. Esophagus 320 to 440μ long by 18 to 24μ in thickness anteriorly, increasing in size after passing the nerve ring, which is located slightly posterior of the middle of the esophagus, and reaching a maximum of 35 to 40μ at the posterior end. Bursa (figs. 79, 80) large when spread out, about three times as wide as the maximum thickness of the body. Border of the median lobe incised in the median line, also with small incisions corresponding to the terminations of the posterior branches of the dorsal ray. Dorsal ray (*d.*, figs. 79, 80) 220 to 400μ long, including a long slender stem 140 to 250μ in length. The branches of the dorsal ray form a somewhat horseshoe-shaped or U-shaped arch, from each of which a ventral branch (*d. v.*, figs. 79, 80) comes off near the middle, and each is cleft at the end. Externolateral ray (*e. l.*, figs. 79, 80) very thick, somewhat thicker than the latero-ventral ray (*l. v.*, figs. 79, 80), which is the thickest of the remaining rays, next in thickness being the medio-lateral ray (*m. l.*, figs. 79, 80), then the postero-lateral (*p. l.*, figs. 79, 80), and ventro-ventral (*v. v.*, figs. 79, 80) rays, which are of about equal thickness, and finally the externo-dorsal ray (*e. d.*, figs. 79, 80) which is the slenderest of the paired rays. Spicules (fig. 81; *sp.*, fig. 79) 240 to 300μ long, of comparatively simple structure, gradually reduced in thickness posteriorly, without prominent projecting edges, corrugations, or excisions.

*Female* 6 to 8 mm. long by 120 to 190μ in maximum thickness in the region of the vulva where there is a more or less prominent belly-like enlargement. Head 28 to 40μ in diameter, varying according to the degree of expansion of the cuticle. Thickness of the body 45 to 75μ at the base of the esophagus, 35 to 50μ at the anus. Esophagus 280 to 415μ in length by 18 to 24μ in diameter anteriorly, the diameter remaining almost equal until the nerve ring is reached, after which it increases, reaching a maximum of 30 to 40μ at the posterior end. Nerve ring slightly posterior of the middle of the esophagus. Tail (fig. 82) slender with rounded tip. Anus (*an.*, fig. 82) about 160μ from the tip of the tail. Beginning some distance in front of the anus the posterior end of the body is gradually reduced in size passing backward, and at a distance of about 75μ from the tip of the tail there is frequently a more sudden decrease, and the posterior portion of the tail thus set off is marked with annular striations. The vulva is located 1.6 to 1.9 mm. from the posterior end of the body. Its shape was not well defined in the specimens examined, but it is apparently elongated transversely. Combined length of the muscular portions of the ovijectors, including the sphincters, about 700μ. Eggs 60 to 80μ long by 30μ wide.

HOSTS.—*Cattle (*Bos taurus*); *sheep (*Ovis aries*); *mountain sheep (*Ovis canadensis*).

LOCATION.—Small intestine.

LOCALITIES COLLECTED.—Europe and United States.

Considerable variation has been noticed in the specimens which I have assigned to the species *Cooperia oncophora*, and it is possible that a division of the species will be necessary. Such a division, however, should be attempted only after a careful comparative study of a larger number of specimens than have been available in the preparation of the present paper.

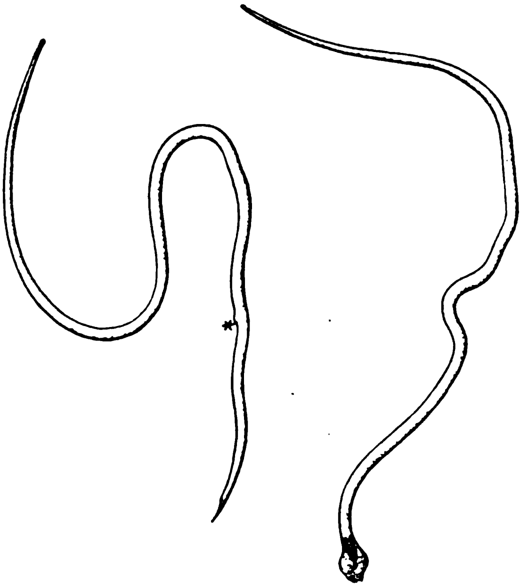


FIG. 83.—*Cooperia pectinata.* Male at right., female at left. *Vulva. × 15. (Original.)

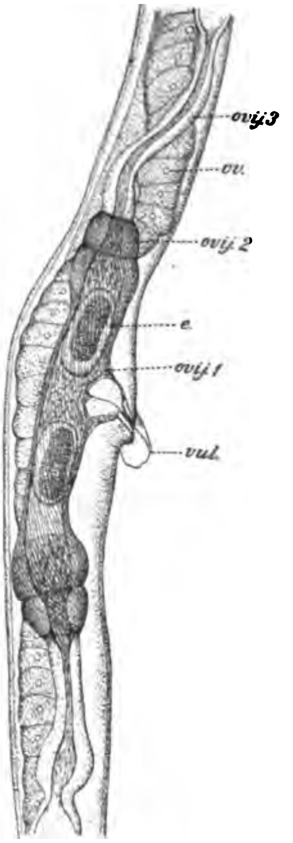


FIG. 85.—*Cooperia pectinata.* Body of female in region of vulva, viewed from right side. *e.*, egg; *ov.*, ovary; *ovij. 1*, terminal portion of ovijector; *ovij. 2*, sphincter of ovijector; *ovij. 3*, nonmuscular portion of ovijector; *vul.*, vulva. × 150. (Original.)

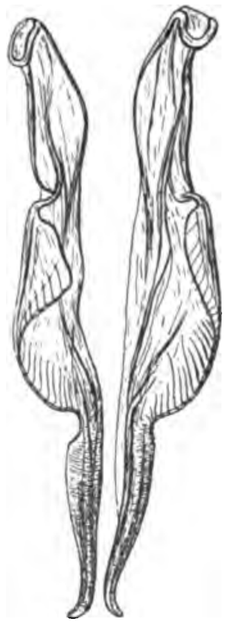


FIG. 84.—*Cooperia pectinata.* Spicules of male. Ventral view. × 300. (Original.)

### **Cooperia pectinata** Ransom, 1907.

(Figs. 83-86.)

1907: *Cooperia pectinata* Ransom, 1907k, pp. 3-4 (from *Bos taurus*, United States).

SPECIFIC DIAGNOSIS.—*Cooperia* (p. 69): *Male* about 7 mm. long by 130 to 160μ in maximum thickness at the base of the bursa. Head about 32μ in diameter, larger if cuticle is expanded. Diameter of body at base of esophagus about 50μ. Esophagus 400μ in length, about 20μ in diameter, increasing in size beyond the nerve ring and reaching its maximum of about 35μ at the posterior end. Nerve ring 280μ from anterior end of esophagus. Latero-ventral and externo-lateral rays of the bursa much thicker than any of the others. Length of dorsal ray including its terminal branches which are parallel to one another and uncleft at the end is at least 180μ. Spicules (fig. 84) 240 to 280μ long, distal third much more slender than remainder, middle third with a prominent curved ventrally-projecting edge corrugated on the inner surface.

*Female* 7.5 to 9 mm. long by 110 to 135μ in maximum diameter in the neighborhood of the vulva. Head 35 to 50μ in diameter, varying according to degree of expansion of the cuticle. Diameter of body at base of esophagus 50 to 60μ, at anus about 40μ. Esophagus 360 to 400μ long, 18 to 24μ in diameter in front of nerve ring, increasing to 35 or 40μ at the posterior end. Nerve ring 250 to 280μ from anterior end of esophagus. Posterior end of body (fig. 86) gradually attenuated backward, beginning at the posterior loop of the posterior ovary or uterus (*ut.*, fig. 86), terminating in a slender sharply pointed tail. Anus (*an.*, fig. 86) about 175μ from the tip of the tail. Vulva (*vul.*, fig. 85) 1.6 to 2 mm. from the tip of the tail, its opening transversely elongated, with projecting vesicular lips. Combined length of muscular portions of ovijectors (*ovij. 1-2*, fig. 85) including the sphincters about 300μ. Musculature of ovijectors only very slightly developed in the region toward the point of union with the vagina. Eggs (*e.*, fig. 85) 70 to 80μ long by 36μ wide.

HOST.—*Cattle (*Bos taurus*).

LOCATION.—Fourth stomach.

LOCALITY COLLECTED.—Texas.

TYPE SPECIMENS.—Bureau of Animal Industry Helminthological Collection No. 4208, collected in 1900 in Texas by Dr. C. W. Stiles.

This species has been collected but once, a few specimens being present

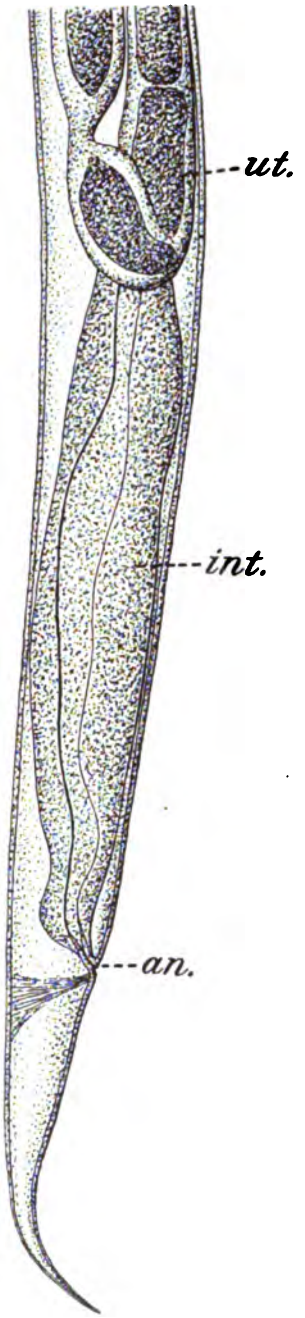


FIG. 86.—*Cooperia pectinata.* Posterior end of body of female, viewed from right side. *an.*, anus; *int.*, intestine; *ut.*, uterus. × 300. (Original.)

among some nematodes taken from the fourth stomach of a Texas cow. These nematodes are mostly *Hæmonchus contortus*, but *Trichostrongylus extenuatus*, *Ostertagia ostertagi*, and *Cooperia punctata* are also represented.

### Genus NEMATODIRUS Ransom, 1907.

1907: *Nematodirus* Ransom, 1907k, p. 4.

GENERIC DIAGNOSIS.—Metastrongylinæ (p. 47): Head not over 50$\mu$ in diameter; circumoral papillæ inconspicuous. Cuticle of head may be slightly inflated and in cervical region striated transversely. Cervical papillæ apparently absent. Bursa without unpaired dorsal median ray. Dorsal lobe of bursa reduced to two small short lobules, each supported by a dorsal ray. Ventro-ventral and latero-ventral rays of each lateral lobe of bursa close together, parallel. Six supporting rays in each lateral lobe. Medio-lateral and postero-lateral rays close together, parallel. Externo-lateral ray distally diverges widely from the other lateral rays. Spicules more than 0.5 mm. in length, slender, tubular, filiform, united by a membrane throughout their length, or only in their distal portion. Gubernaculum absent. Vulva of female behind the middle of the body. Ovijectors well developed. Eggs large, generally over 150$\mu$ long.

TYPE-SPECIES.—*Nematodirus filicollis* (Rudolphi, 1802) Ransom, 1907.

Three species which may be assigned to the genus *Nematodirus* have been reported as parasites of ruminants.

KEY TO SPECIES OF NEMATODIRUS.

1. Length of spicules of male about 1 mm.; tail of female blunt; eggs more than 150$\mu$ long .......................................................... 2
   Length of spicules of male about 4.5 mm.; tail of female pointed; eggs 97$\mu$ long by 53$\mu$ wide; male 24 mm. long, female 29 mm. long. *Nematodirus digitatus*, p. 85
2. Eggs 170 to 200$\mu$ long; male 8 to 15 mm. long, female 12 to 20 mm. long. *Nematodirus filicollis*, p. 82
   Eggs about 260$\mu$ long; male 14 to 19 mm. long, female 26 to 29 mm. long. *Nematodirus spathiger*, p. 85

### Nematodirus filicollis (Rudolphi, 1802) Ransom, 1907.

(Figs. 87-92.)

1802: *Ascaris filicollis* Rudolphi, 1802a, pp. 23-25, pl. 1, fig. 1, a, b, c (from *Ovis aries*, Germany).

1803: *Strongylus filicollis* (Rudolphi, 1802) Rudolphi, 1803a, pp. 17-18.

1803: *Fusaria filicollis* (Rudolphi) Zeder, 1803a, p. 110 (*Ascaris filicollis* Rudolphi, 1802, renamed).

1907: *Nematodirus filicollis* (Rudolphi) Ransom, 1907k, p. 4.

SPECIFIC DIAGNOSIS.—*Nematodirus* (p. 82): Body slender, tapering gradually toward the anterior extremity; head (fig. 88) between 25 and 50$\mu$ in diameter; cuticle of head and neck may be slightly inflated, in latter region coarsely striated transversely, elsewhere without transverse striations. Four and probably six inconspicuous circumoral papillæ. Mouth small, followed directly by the esophagus, no buccal capsule. Esophagus 400 to 500$\mu$ long. Cervical papillæ not apparent. Lateral membranes absent.

*Male* 8 to 15 mm. long by 125 to 175$\mu$ in maximum diameter. Bursa (figs. 89, 90) with two large lateral lobes. Dorsal lobe short, deeply emarginate, and thus reduced

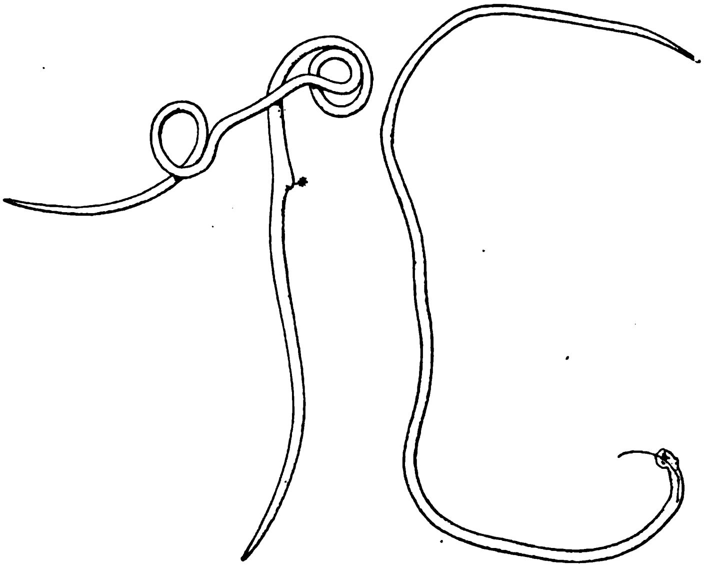


FIG. 87.—*Nematodirus filicollis*. Male at right, female at left. *Vulva. × 15. (Original.)

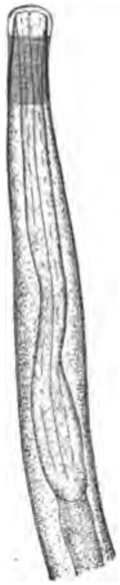


FIG. 88.—*Nematodirus filicollis*. Anterior end of body. × 150. (Original.)

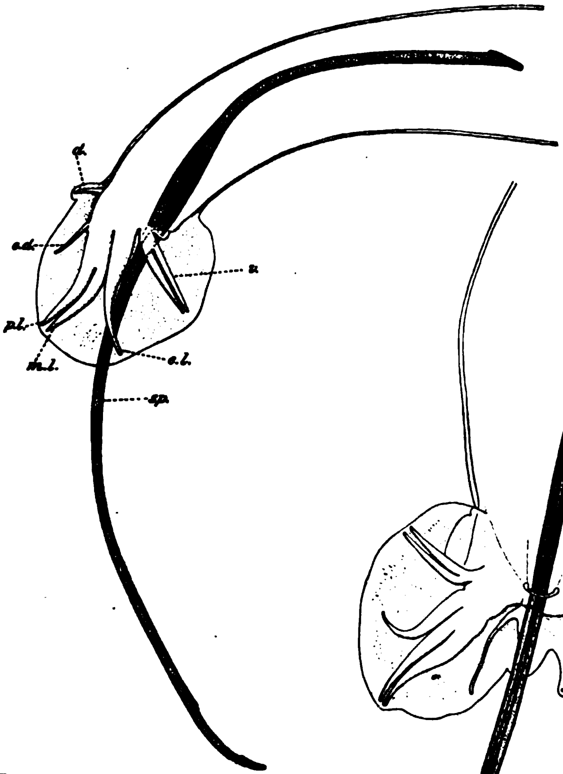


FIG. 90.—*Nematodirus filicollis*. Posterior end of body of male, viewed from right side. *d.*, dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *sp.*, spicule; *v.*, ventral rays. × 150. (Original.)

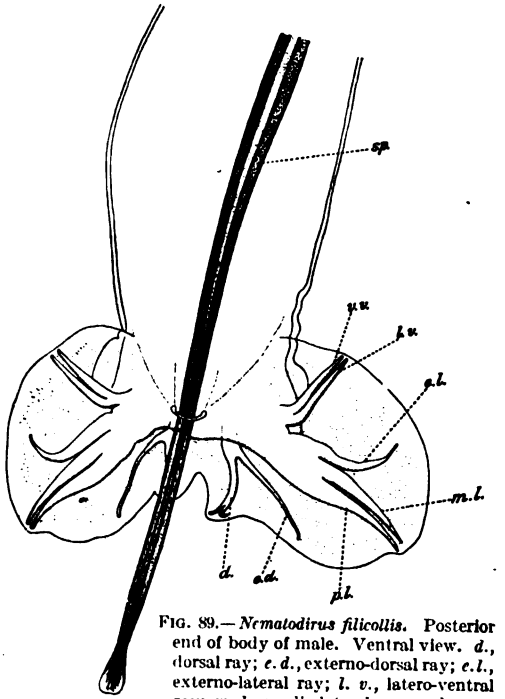


FIG. 89.—*Nematodirus filicollis*. Posterior end of body of male. Ventral view. *d.*, dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *sp.*, spicules; *v. v.*, ventro-ventral ray. × 150. (Original.)

to two small lobules. Ventral rays (*v. v.*, *l. v.*, *v.*, figs. 89, 90) slender, close together, parallel. Externo-lateral ray (*e. l.*, figs. 89, 90) at first close to the medio-lateral ray (*m. l.*, figs. 89, 90), distally curves ventralward away from the latter. Distally the medio-lateral and postero-lateral (*p. l.*, figs. 89, 90) rays curve slightly dorsalward. Medio-lateral and postero-lateral rays close together throughout their entire length, the tip of the latter extending slightly beyond that of the former. Tip of the postero-lateral ray about equidistant from the tip of the externo-dorsal ray and the tip of the externo-lateral ray, the latter being about the same distance from the tip of the latero-ventral ray. Lateral rays thicker than the other rays. Externo-dorsal ray (*e. d.*, figs. 89, 90) very slender. No median dorsal ray. Each dorsal lobule of the bursa is sustained by a ray (*d.*, figs. 89, 90) whose base is united with the base of the externo-dorsal ray, somewhat thicker than the latter, with bifid tip. Spicules (*sp.*, figs. 89, 90) slender, equal, about 1 mm. long, united by a membrane in the posterior two-thirds, more closely toward the tip, where the membrane forms a spatulate enlargement. Prebursal papillæ small, inconspicuous.

*Female* 12 to 20 mm. long with a maximum thickness of 200 to 250$\mu$ at the vulva. Thickness suddenly reduced just behind the vulva. Tip of tail (fig. 92) truncate, bearing a short slender acutely pointed bristle-like process. Anus (*an.*, fig. 92) 70 to 80$\mu$ from the truncated end of the body. Vulva (*vul.*, fig. 91) a transverse slit located about one-third the length of the body from the posterior end. Combined length of the muscular portions of the two ovijectors (*ovij. 1–2*, fig. 91) including the sphincters about 400$\mu$. Eggs (*e.*, fig. 91) oval, 175 to 200$\mu$ long by about 100$\mu$ wide. Embryos develop into filariform larvæ before hatching.

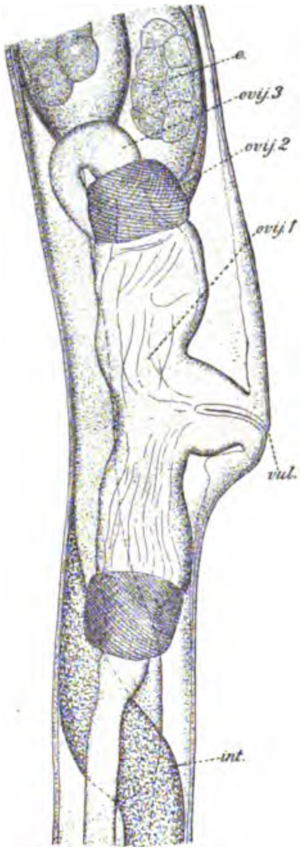


FIG. 91.—*Nematodirus filicollis.* Body of female in region of vulva, viewed from right side. *e.*, egg; *int.*, intestine; *ovij. 1*, terminal portion of ovijector; *ovij. 2*, sphincter of ovijector; *ovij. 3*, nonmuscular portion of ovijector; *vul.*, vulva. × 150. (Original.)

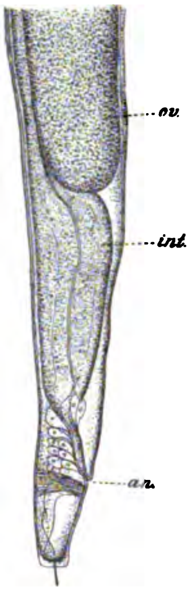


FIG. 92.—*Nematodirus filicollis.* Posterior end of body of female, viewed from right side. *an.*, anus; *int.*, intestine; *ov.*, ovary. × 150. (Original.)

HOSTS.—*Cattle (*Bos taurus*); *sheep (*Ovis aries*); *goat (*Capra hircus*); *prong-horned antelope (*Antilocapra americana*); *roe deer (*Capreolus capreolus*); fallow deer (*Dama dama*).

LOCATION.—Small intestine.

LOCALITIES COLLECTED.—United States, Europe, New Zealand, Australia.

This species is of rather common occurrence in the United States, but as a rule is not found in large numbers, and probably in consequence does not seriously affect the health of animals which it infests. An interesting point in regard to its development is that the embryo develops into a larva with the filariform type of esophagus before hatching, thus differing from other strongyles, such as *Hæmonchus contortus*, in which the newly hatched embryo possesses a rhabditiform esophagus with posterior bulb, not developing into the larval stage with filariform esophagus until later.

### **Nematodirus spathiger** (Railliet, 1896) Railliet and Henry, 1909.

1896: *Strongylus spathiger* Railliet, 1896m, p. 490.
1909: *Nematodirus spathiger* (Railliet) Railliet and Henry, 1909a, p. 87.

SPECIFIC DIAGNOSIS.—*Nematodirus* (p. 82): Color reddish. Body much attenuated anteriorly. Head provided with an expansion. Mouth bordered by membranous lips. Esophagus very long, claviform.

*Male* 14 to 19 mm. long and 180 to 200μ in maximum thickness. Its maximum thickness is attained toward the posterior third of the body. Bursa with lateral lobes well developed; posterior lobe so deeply emarginate that it is reduced to two weakly developed lobules. Each dorsal lobule supported by a dorsal ray, which is divided distally into two branches, of which the outer one is slightly the longer and curved outward. Externo-dorsal ray very slender. The spicules, united at their extremity by a spatulate membranous lamella, measure 1 mm. in length.

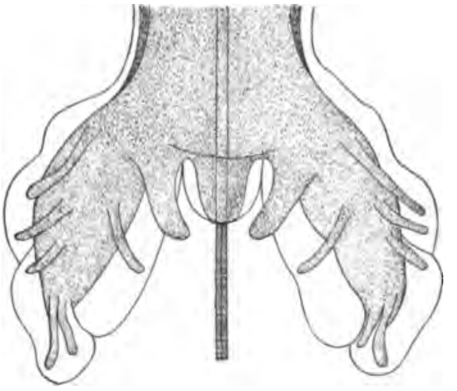


FIG. 93.—*Nematodirus digitatus*. Posterior end of body of male. Enlarged. (After Linstow, 1906, pl. 1, fig. 10.)

*Female* 26 to 29 mm. long, gradually increasing in thickness until the vulva is reached, in which region the body measures as much as 460μ. Immediately behind the vulva the body is reduced in size, then increased again in the region of the posterior oviduct, and finally diminishes in size toward the tip of the tail, which is very blunt. Vulva situated about one-fourth the length of the body from the posterior end. Eggs very large, ovoid-oblong, with thin shells a little thickened at one pole; average size 260μ long by 103μ wide; in course of segmentation when deposited.

HOST.—Arabian camel (*Camelus dromedarius*).

LOCATION.—Small intestine.

LOCALITY COLLECTED.—France.

The foregoing diagnosis is based on Railliet's (1896m) brief description.

### **Nematodirus digitatus** (Linstow, 1906) Railliet and Henry, 1909.

(Fig. 93.)

1906: *Strongylus digitatus* Linstow, 1906, Spolia Zeylanica, Colombo, pt. 11, v. 3, Jan., pp. 163, 168, pl. 1, fig. 10 (from stomach of *Bibos indicus* (=*Bos indicus*), Ceylon).
1909: *Nematodirus digitatus* (Linstow) Railliet and Henry, 1909a, p. 87.

SPECIFIC DIAGNOSIS.—*Nematodirus* (p. 82): Cuticle without longitudinal lines, but with very fine annulation; head attenuate, mouth surrounded by four papillæ; esophagus of male $\frac{1}{14}$, of female $\frac{1}{17}$ the body length; the nerve ring surrounds the esophagus at the limit of the first and second quarters and the excretory pore opens below it.

*Male* 24 by 0.36 mm.; spicules very long, 4.54 mm., coalescent throughout their entire length and thickened fusiform at the end; the lateral lobes of the bursa are curved claw-like inwardly; each lobe is supported by six ribs, of which one lies at the inner margin, two side by side at the outer margin; there is no median lobe; the end of the body is rounded with a pair of finger-shaped, slightly curved hyaline cuticular lobes. (?=lobules of the reduced dorsal median lobe—B. H. R.)

*Female* 29 by 0.47 mm.; genital orifice lies far back, dividing the body in the ratio 8 : 1; tail pointed, $\frac{1}{188}$ the body length; eggs 97 by 53$\mu$.

HOST.—Zebu (*Bos indicus*).

LOCATION.—Stomach.

LOCALITY COLLECTED.—Ceylon.

The foregoing description is taken from Linstow (1906, Spolia Zeylanica, Colombo, pt. 11, v. 3, Jan., p. 163). He remarks particularly upon one difference between this species and *Nematodirus filicollis*, namely, the absence of longitudinal lines on the cuticle of the former, and the presence of 18 longitudinal ridges in the latter.

### Genus TRICHOSTRONGYLUS Looss, 1905.

1905: *Trichostrongylus* Looss, 1905o, pp. 409–422, pls. 1–2, figs. 1–14.

GENERIC DIAGNOSIS.—Metastrongylinæ (p. 47): Small and slender; color reddish. Body gradually attenuated forward from the genital opening. Head only about 10$\mu$ in diameter, with three small lips and nodular or punctiform papillæ. Cuticle with annular striations and without longitudinal ridges. Cervical papillæ lacking. Buccal cavity not well differentiated. Esophagus long, with simple well-developed dorsal gland. Nerve ring and excretory pore about 150$\mu$ from the anterior end. Body of the cervical glands behind the esophagus, one in front of the other. Bursa with large lateral lobes, without well-developed median lobe. Six supporting rays in each lateral lobe. Ventral rays widely separated, of very different thickness. Ventro-ventral ray thin and directed ventrally; latero-ventral ray thick and in close relation with the lateral rays. Postero-lateral ray thinner than the other lateral rays and located close to the externo-dorsal ray. Dorsal ray short, cleft at the end. Spicules short, not twisted, but spoon-shaped or spatula-shaped. Anterior end of spicule thickened, with a knob-like or disk-like process toward one side. Toward the posterior end of the spicule a more or less prominent angular projection is usually present, giving the point of the spicule a hooked or barbed appearance. Gubernaculum or accessory piece present, elongated and boat-shaped or shoe-shaped in profile. Prebursal papillæ small. Testicle simple, uncoiled. Ovaries in older individuals slightly wavy, the anterior one disposed in one or several longitudinal loops. Ovijectors well developed. Vulva in the posterior half of the body, slit-shaped, straight or crescentic, surrounded by somewhat protruding chitinous lips. Postanal portion of the body of female relatively short, with a pair of small caudal papillæ near the tip. Eggs of moderate size, thin shelled, colorless, containing a maximum number of 8 to 32 cells when deposited. Parasitic in the duodenum, more rarely in the stomach of herbivorous animals.

TYPE SPECIES.—*Trichostrongylus retortæformis* (Zeder, 1800) Looss, 1905.

Nematodes of the genus *Trichostrongylus* often occur in ruminants in enormous numbers. In autopsies of goats dying with symptoms of parasitic disease I have found the small intestine and fourth stomach containing large felt-like masses of worms, composed mostly of *Trichostrongylus instabilis* in the intestine and *T. extenuatus* in the fourth stomach. The latter species has been found associated with gastro-enteritis in cattle in England by McFadyean (1896b).

This genus is of interest to human medicine, as three of its species, *T. instabilis*, *T. probolurus*, and *T. vitrinus*, occur parasitic in man as well as in ruminants. Although all three occur in the United States, they have not yet been reported as parasites of man in this country.

Six species of *Trichostrongylus* are known to be parasitic in ruminants.

### KEY TO SPECIES OF TRICHOSTRONGYLUS.

(The imperfectly known *Trichostrongylus colubriformis* (p. 90) is not included in this key.)

1. Spicules of male unequal in size, right spicule 85 to 95μ long, left spicule 110 to 120μ long; gubernaculum 50 to 60μ long; postero-lateral ray of bursa as long as either of the other two lateral rays and nearly as wide; male 3.4 to 4.4 mm. long, female 4.6 to 5.5 mm. long........ *Trichostrongylus extenuatus*, p. 94

   Spicules of male equal in size, more than 125μ in length; postero-lateral ray of bursa usually considerably shorter and narrower than the other lateral rays..... 2

2. Spicules 160 to 170μ long, sharply pointed, without hook-like projection; bursa relatively large; externo-lateral ray widest of the rays; male 4 to 4.5 mm. long, female 5 to 6.5 mm. long........................ *Trichostrongylus vitrinus*, p. 92

   Spicules less than 150μ long........................................ 3

3. Spicules with a hook-like projection on the ventral surface near the tip; postero-lateral ray of bursa much shorter than the other lateral rays.............. 4

   Spicules without hook-like projection, distal half bent ventralward at an angle of about 140 degrees; spicules 130 to 145μ long; latero-ventral ray of bursa longest and widest of the rays; postero-lateral ray nearly as long as the other lateral rays; male 4.3 to 4.9 mm. long, female 5.8 to 6.8 mm. long.
   *Trichostrongylus capricola*, p. 96

4. Spicules relatively thick, 126 to 134μ long, hook-like projection high and sharply defined, in front of it a second angular projection, giving the spicules a gnarled or twisted appearance under low magnification; latero-ventral ray of bursa much the thickest of the rays; postero-lateral and external-dorsal ray very short and close together; tail of female short and rather blunt; male 4.5 to 5.5 mm. long, female 4.5 to 6 mm. long.................... *Trichostrongylus probolurus*, p. 90

   Spicules relatively slender, 135 to 145μ long, hook-like projection sharply defined but not high; externo-lateral ray usually thicker than any of the others, rarely of about the same thickness as the latero-ventral ray; tail of female rather slender, sharply pointed; male 4 to 5.5 mm. long, female 5 to 6 mm. long.
   *Trichostrongylus instabilis*, p. 88

### Trichostrongylus instabilis (Railliet, 1893) Looss, 1905.

(Figs. 94-97.)

1892: *Strongylus colubriformis* Giles, 1892c, p. 34 (possibly identical with *T. instabilis*).
1893: *Strongylus instabilis* Railliet, 1893a, p. 442, fig. 301.
1895: *Strongylus subtilis* Looss, 1895b, pp. 161-169, pl. 1, figs. 1-8.
1898: *Strongylus retortæformis* Zeder of Railliet, 1898b, p. 174 (in part).
1905: *Trichostrongylus subtilis* Looss, 1905o, pp. 417, 418-419, pl. 1, figs. 4-8.
1905: *Trichostrongylus instabilis* (Railliet, 1893), Looss, 1905o, p. 422.

SPECIFIC DIAGNOSIS.—*Trichostrongylus* (p. 86): *Male* 4 to 5.5 mm. long and about 80μ thick in front of bursa. The externo-lateral ray (*e. l.*, fig. 95) is usually thicker (lateral view) than any of the others, rarely of about the same thickness as the latero-ventral ray (*l. v.*, fig. 95). Postero-lateral ray (*p. l.*, fig. 95) noticeably smaller than the other lateral rays and closer to the externo-dorsal ray (*e. d.*, fig. 95) than to the other lateral rays; its end is often bent toward that of the externo-dorsal ray, so that the distance between the postero-lateral and externo-dorsal papillæ is less than that between the latter and the dorsal ray. Dorsal ray (*d.*, fig. 95) split near the end, each branch ending in a double point. Spicules (fig. 96) 135 to 145μ long. Gubernaculum about 70μ long, of bright yellowish-brown color, and relatively slender. Terminal hook of the spicules long and sharply defined, but not high.

*Female* 5 to 6 mm. long, 80μ wide at the level of the genital opening (1.05 to 1.2 mm. from tip of tail). Body becomes but slightly thinner toward the anus (*an.*, fig. 97), behind which it narrows rather suddenly to form a slender and very sharp tail. The latter is often bent a little dorsalward. Distance between anus and tip of tail 55 to 70μ. Vulva elongated longitudinally, relatively short, 50 to 55μ long, including its lips. Combined length of muscular portions of ovijectors, including the sphincters, 400 to 500μ. Eggs 73 to 76μ, rarely 80μ, long, and 40 to 43μ wide.

HOSTS.—*Sheep (*Ovis aries*); Dorcas gazelle (*Gazella dorcas*); *Arabian camel (*Camelus dromedarius*); *Bactrian camel (*Camelus bactrianus*); Arabian baboon (*Papio hamadryas*); man (*Homo sapiens*); *goat (*Capra hircus*); *prong-horned antelope (*Antilocapra americana*); *roe deer (*Capreolus capreolus*); *bharal (*Ovis nahura*).

LOCATION.—Duodenum, more rarely stomach (fourth stomach of ruminants).

LOCALITIES COLLECTED.—North Africa, Europe, Japan, United States, ? India.

This species is so closely similar to *Strongylus colubriformis* Giles, 1892, that it is very probable that the two are identical. Looss (1905o), however, considers that since there are certain discrepancies between Giles's (1892d, pp. 45-47, 49, figs. 1-9) description and figures on the one hand, and *Trichostrongylus instabilis* on the other, a further study of *Strongylus colubriformis* will be necessary to settle the question as to whether the two forms are identical or not. In view of the fact, therefore, that Giles's description and figures of *Strongylus colubriformis* in certain important respects do not correspond to *Trichostrongylus instabilis*, which may or may not be due to inaccuracies on the part of Giles, the name *Trichostrongylus instabilis* may be retained until more certain evidence as to the identity of the two forms can be procured.

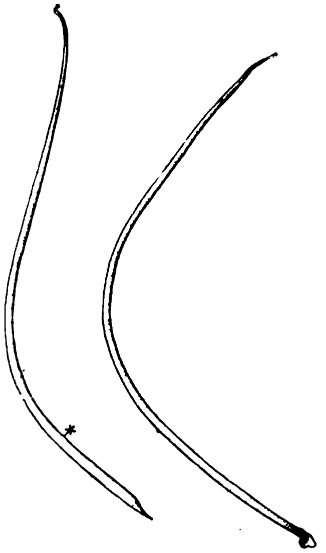


FIG. 94.— *Trichostrongylus instabilis.* Male at right, female at left. *Vulva. × 15. (Original.)

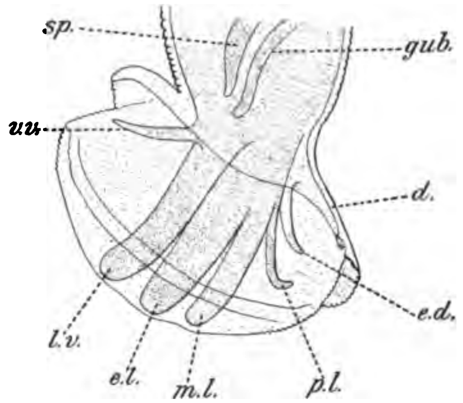


FIG. 95.— *Trichostrongylus instabilis.* Posterior end of body of male viewed from left side. *d.*, dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *gub.*, gubernaculum; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *sp.*, portion of spicule; *v. v.*, ventro-ventral ray. × about 300. (After Looss, 1905o, pl. 1, fig. 4.)

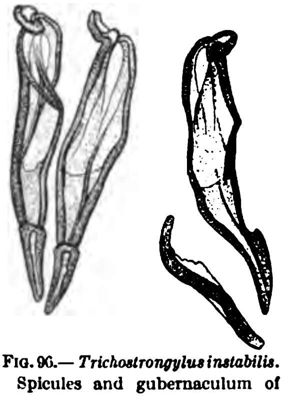


FIG. 96.— *Trichostrongylus instabilis.* Spicules and gubernaculum of male. Ventral view at left, lateral view at right. × about 300. (After Looss, 1905o, pl. 1, fig. 6.)

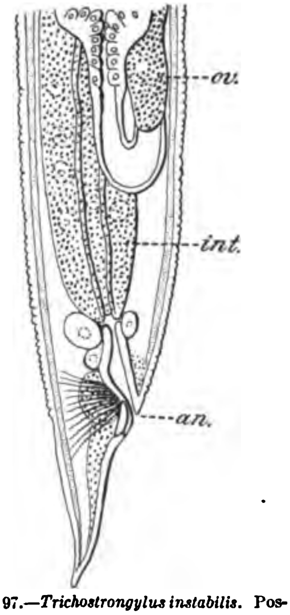


FIG. 97.—*Trichostrongylus instabilis.* Posterior end of body of female, viewed from right side. *an.*, anus; *int.*, intestine; *ov.*, ovary. × about 300. (After Looss, 1905o, pl. 1, fig. 8.)

### **Trichostrongylus colubriformis** (Giles, 1892) Ransom, 1911.

1892: *Strongylus colubriformis* Giles, 1892c, p. 34; 1892d, pp. 45–47, 49, figs. 1-9 (in small intestine, *Ovis aries*, India).

1911: *Trichostrongylus colubriformis* (Giles) Ransom, 1911, pp. 14, 87, 90, 122 (the present paper).

SPECIFIC DIAGNOSIS.—*Trichostrongylus* (p. 86): Male nearly 6 mm. in length, 130μ in thickness. Female about 8 mm. in length and of about the same thickness as the male. Body dark colored, the female usually straight, the male more usually contorted. Both sexes have the head extremely attenuated and become progressively thicker as the caudal extremity is approached; but while in the male the thickest part is quite at the caudal extremity, the female is thickest opposite the vulva, which is placed one-fifth of the entire body's length from the mucronate extremity of the tail. Mouth entire; quite unarmed. The female is provided with a pair of semielliptic alæ, situated opposite the neck which is markedly constricted, giving her the outline of a cobra.

Bursa of male deeply bilobed, the dorsal cleft being almost as deep as the ventral, so that the organ looks like a mussel shell, placed transversely, and attached to the worm at the hinge. Ventral costa small, the lateral and ventro-lateral costæ stout, subequal and forming a closely packed group; dorsal and dorso-lateral costæ small.

Ova (intra-uterine) elliptical, 90μ long by 46μ wide. A more advanced ovum, apparently mature, measured 110μ. Vulva opens into the middle of a sort of cylindrical sac [ovijectors] which extends for a short distance forward and backward from the vaginal opening. The connection between the vagina and the uterine canals is effected by means of a thick chitinous, valvular apparatus, which closely resembles the esophageal bulb of certain nematodes, and, on high-power examination, is seen to be of a most complicated structure, the chitinous lining of the vagina projecting up into the end of the lax uterine canal and having a deeply sinuate margin. Surrounding this structure is a very thick muscular ring, which gives the bulb-like outline to the whole apparatus.

HOST.—Sheep (*Ovis aries*).

LOCATION.—Small intestine.

LOCALITY COLLECTED.—India.

The foregoing description is taken almost verbatim from Giles (1892d). *Trichostrongylus colubriformis* is very similar to if not identical with *T. instabilis* as already noted in the discussion of the latter species. The spicules of the former, as shown in Giles's figure 6, are exactly similar to those of *T. instabilis*, and, judging from the size of the figure and the scale of magnification, they have also the same length as the spicules of the latter species. Giles's drawing of the posterior end of the female also shows a great similarity to *T. instabilis*. The other drawings are less striking in their resemblance to *T. instabilis*, and some of them would not apply at all to this species unless it is assumed that they were inaccurately drawn.

### **Trichostrongylus probolurus** (Railliet, 1896) Looss, 1905.

(Figs. 98–101)

1896: *Strongylus probolurus* Railliet, 1896o, p. 542.

1905: *Trichostrongylus probolurus* (Railliet) Looss, 1905o, pp. 414, 417, 419–421, 422, pl. 2, figs. 9–11.

SPECIFIC DIAGNOSIS.—*Trichostrongylus* (p. 86): *Male* 4.5 to 5.5 mm. long and about 80μ wide at the beginning of the bursa. The latero-ventral ray (*l. v.*, fig. 99) is by far the widest of the rays (lateral view). The externo-lateral ray (*e. l.*, fig. 99) wider than the medio-lateral ray (*m. l.*, fig. 99). The postero-lateral (*p. l.*, fig. 99) and externo-dorsal (*e. d.*, fig. 99) rays are remarkably short and close together. The end of the former is turned back so far dorsally that the postero-lateral papilla on the inner

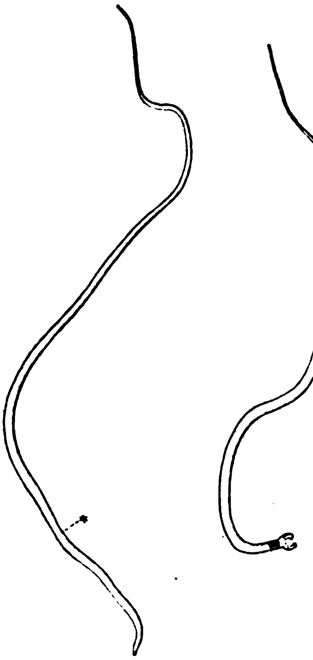


FIG. 98.—*Trichostrongylus probolurus*. Male at right, female at left. *Vulva. × 15. (Original.)

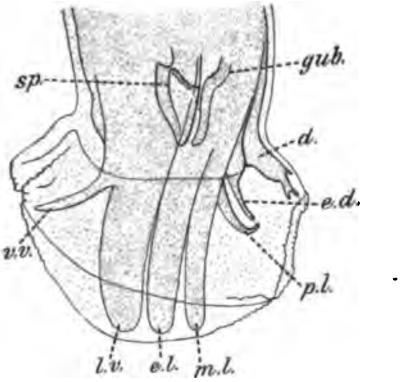


FIG. 99.—*Trichostrongylus probolurus*. Posterior end of body of male viewed from left side. *d.*, dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *gub.*, portion of gubernaculum; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *sp.*, portion of spicule; *p. v.*, ventro-ventral ray. × about 300. (After Looss, 1905o, pl. 2, fig. 9.)

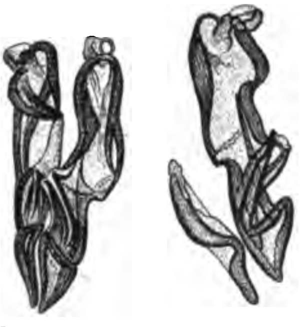


FIG. 100.—*Trichostrongylus probolurus*. Spicules and gubernaculum of male. Ventral view at left, lateral view at right. × about 300. (After Looss, 1905o, pl. 2, fig. 10.)

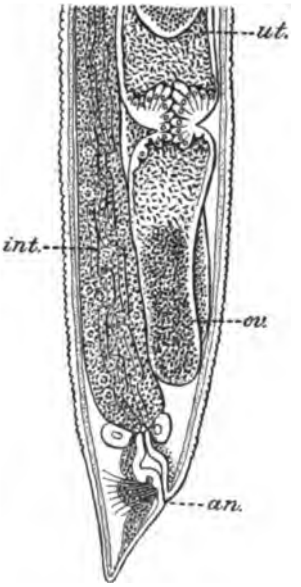


FIG. 101.—*Trichostrongylus probolurus*. Posterior end of body of female, viewed from right side. *an.*, anus; *int.*, intestine; *ov.*, ovary; *ut.*, uterus. × about 300. (After Looss, 1905o, pl. 2, fig. 11.)

side of the bursa is directly opposite to or even somewhat dorsal of the externo-dorsal papilla upon the outer side of the bursa. Stem of the dorsal ray (*d.*, fig. 99) very short, divided as in *T. instabilis*. Spicules (fig. 100) 126 to 134μ long and relatively thick. Gubernaculum 75 to 80μ long, usually of a brilliant deep-brown color. Terminal hook of the spicule very high and sharply defined. In front of it on the ventral edge of the spicule is a second angular pointed projection, which together with the terminal hook when observed under low magnification, gives the spicule a gnarled or twisted appearance.

*Female* 4.5 to 6 mm. long and about 80μ wide at the level of the vulva (1.08 to 1.25 mm. from the tail according to age). Posterior portion of the body (fig. 101) rather plump, becomes narrower beginning a very short distance in front of the anus, and rapidly diminishes in thickness, thus forming a short rather blunt tail, which commonly is turned diagonally upwards, or may be straight, or bent ventrally. Distance between tip of tail and anus (*an.*, fig. 101) 40 to 50μ. Vulva including its chitinous border 76μ long, elongated longitudinally, straight or slightly curved. Combined length of muscular portions of ovijectors including the sphincters about 375μ. Eggs 76 to 80μ long by 43 to 46μ wide.

HOSTS.—Sheep (*Ovis aries*); Dorcas gazelle (*Gazella dorcas*); man (*Homo sapiens*); Arabian camel (*Camelus dromedarius*); *Bactrian camel (*Camelus bactrianus*).

LOCATION.—Duodenum.

LOCALITIES COLLECTED.—North Africa, Europe, United States.

This species has been found but once in the United States, having been collected from a camel which died at the National Zoological Park, Washington, D. C.

### **Trichostrongylus vitrinus** Looss, 1905.

(Figs. 102-105.)

1905: *Trichostrongylus vitrinus* Looss, 1905o, p. 421, pl. 2, figs. 12-14.

SPECIFIC DIAGNOSIS.—*Trichostrongylus* (p. 86): *Male* usually between 4 and 5.5 mm. long, and about 85μ wide in front of bursa. Bursa (fig. 103) noticeably larger than in the other species of *Trichostrongylus* discussed in the present paper, the lateral lobes at their base being 140 to 180μ broad in the dorso-ventral direction. Rays relatively more slender and straighter than in other species. The externo-lateral ray (*e. l.*, fig. 103) is the widest. Ventro-ventral (*v. v.*, fig. 103) and postero-lateral (*p. l.*, fig. 103) rays of equal width, straight and reaching nearly to the edge of the bursa. Externo-dorsal ray (*e. d.*, fig. 103) short, its terminal papilla about halfway between the papilla of the postero-lateral ray and the middle of the dorsal ray. Unpaired portion of the latter (*d.*, fig. 103) relatively long, each of its branches usually ending in a simple point. Spicules (fig. 104) 160 to 170μ long and gubernaculum 85 to 95μ long, both of bright yellowish-brown color. The spicules end in a very sharp point, without definite hook-like projection.

*Female* usually between 5 and 6.5 mm. long, 84 to 92μ wide at the level of the genital opening (1.15 to 1.25 mm. from the tip of the tail). Cuticle in the neighborhood of the vulva with irregular thickenings, absent or only slightly marked in young individuals, but always present in old ones. Vulva short, more or less crescentic, and usually placed diagonally to the axis of the body and raised a little above the level of the surface. Posterior end of the body (fig. 105) is noticeably narrowed behind the level of the loop of the posterior ovary (*ov.*, fig. 105), and then remains nearly cylindrical until the anus is reached, behind which it is reduced rapidly and symmetrically, so that the anus (*an.*, fig. 105) projects in a well marked angle. Tail (behind anus) usually bowed dorsalward. Combined length of muscular portions of ovijectors including the sphincters about 450μ. Eggs 84 to 90μ long by 46 to 50μ wide.

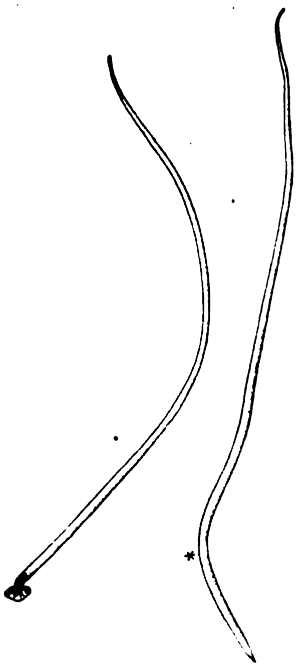


FIG. 102.— *Trichostrongylus vitrinus.* Male at left, female at right. *Vulva. × 15. (Original.)

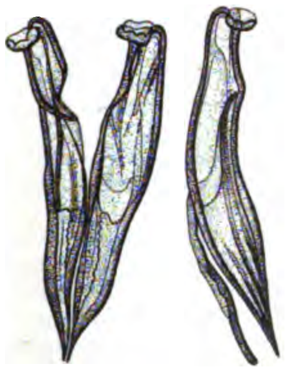


FIG. 104.— *Trichostrongylus vitrinus.* Spicules and gubernaculum of male. Ventral view at left, lateral view at right. × about 300. (After Looss, 1905o, pl. 2, fig. 13.)

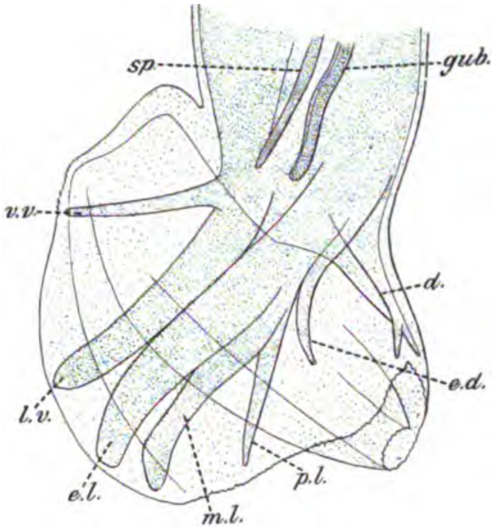


FIG. 103.— *Trichostrongylus vitrinus.* Posterior end of body of male viewed from left side. *d.*, dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *gub.*, portion of gubernaculum; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *sp.*, portion of spicule; *v. v.*, ventro-ventral ray. × about 300. (After Looss, 1905o, pl. 2, fig. 12.)

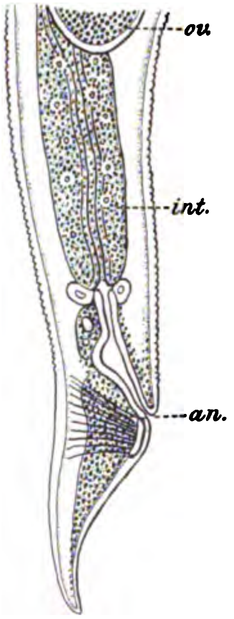


FIG. 105.— *Trichostrongylus vitrinus.* Posterior end of body of female, viewed from right side. *an.*, anus; *int.*, intestine; *ov.*, ovary. × about 300. (After Looss, 1905o, pl. 2, fig. 14.)

HOSTS.—* Sheep (*Ovis aries*); Arabian camel (*Camelus dromedarius*); man (*Homo sapiens*); * goat (*Capra hircus*).

LOCATION.—Duodenum, and in ruminants occasionally in the fourth stomach.

LOCALITIES COLLECTED.—Europe, Africa, and United States.

This species has been found several times in small numbers in sheep and goats in the eastern United States, associated with other species of *Trichostrongylus*.

### **Trichostrongylus extenuatus** (Railliet, 1898) Ransom, 1907.

(Figs. 106–111.)

1896: *Strongylus gracilis* McFadyean, 1896b, pp. 319–320, pl. 4, figs. 6–8. (Not *Strongylus gracilis* F. S. Leuckart, 1842.)

1898: *Strongylus extenuatus* Railliet, 1898c, p. 254. (*S. gracilis* McFadyean 1896, renamed.)

1901: *Strongylus retortæformis* Zeder of Stödter, 1901a, pp. 69, 75, 76, 77, 78, 79, 80, 81, 82, 84, 85, 92, 95, 96, pl. 11, figs. 6–8, pl. 12, figs. 1–12 (in part).

1907: *Trichostrongylus extenuatus* (Railliet, 1898) Ransom, 1907k, p. 2.

SPECIFIC DIAGNOSIS.— *Trichostrongylus* (p. 86): *Male* 3.4 to 4.4 mm. long by 50 to 60μ thick in front of bursa. The ventro-ventral ray of the bursa (*v. v.*, figs. 107, 108) is very slender. The latero-ventral (*l. v.*, figs. 107, 108), externo-lateral (*e. l.*, figs. 107, 108) and medio-lateral (*m. l.*, figs. 107, 108) rays are of about equal thickness and the postero-lateral ray (*p. l.*, figs. 107, 108) slightly narrower. The latter is relatively much wider than in any of the other species of this genus occurring in ruminants, and also longer, extending nearly to the edge of the bursa. The externo-dorsal ray (*e. d.*, figs. 107, 108) is narrower and much shorter than the postero-lateral ray. Tips of the medio-lateral and postero-lateral rays closer together than those of any of the others. Dorsal ray (*d.*, figs. 107, 108) relatively long and slender, divided at the tip into two branches, each of which is also divided into two. Spicules (figs. 109, 110) yellowish-brown. An angular projection on the ventral surface of each spicule about 65μ from the anterior end. Beyond this projection the right spicule terminates in a short point, the left spicule in a long slender point, usually somewhat crooked. The two spicules are thus dissimilar, the right spicule measuring 85 to 95μ in length, the left spicule 110 to 120μ. A slender, tapering, pointed, longitudinal process is given off from the inner side of each spicule near the middle. The gubernaculum (*gub.*, figs. 109, 110) is similar in color to the spicules and measures 50 to 60μ in length. It usually lies dorsal of the right spicule in such a way as to give the latter the appearance on casual observation of terminating in a slender point like the left spicule.

*Female* 4.6 to 5.5 mm. in length by 55 to 70μ in maximum thickness in the region of the vulva, which is located 0.8 to 1 mm. from the tip of the tail. Vulva 50 to 60μ long, elongated longitudinally, with highly refractive chitinous lips. Posterior end of body (fig. 111) tapers gradually behind the loop of the posterior ovary (*ov.*, fig. 111) and more rapidly behind the anus (*an.*, fig. 111) which is located 60 to 90μ from the tip of the tail. The tail is usually straight. Combined length of muscular portions of ovijectors 230 to 300μ. The eggs measure 70 to 80μ in length by 35 to 45μ in width.

HOSTS.—*Cattle (*Bos taurus*); *sheep (*Ovis aries*); *goat (*Capra hircus*); *bharal (*Ovis nahura*); *Mexican mountain sheep (*Ovis mexicana*); *prong-horned antelope (*Antilocapra americana*); *mule deer (*Odocoileus hemionus*); *roe deer (*Capreolus capreolus*); *Newfoundland caribou (*Rangifer terrænovæ*).

LOCATION.—Fourth stomach, more rarely anterior end of small intestine.

LOCALITIES COLLECTED.—United States, Australia, and Europe.

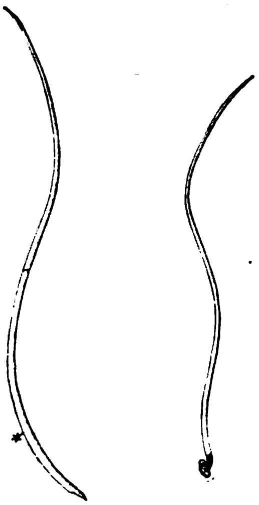


FIG. 106.—*Trichostrongylus extenuatus.* Male at right, female at left. * Vulva. × 15. (Original.)

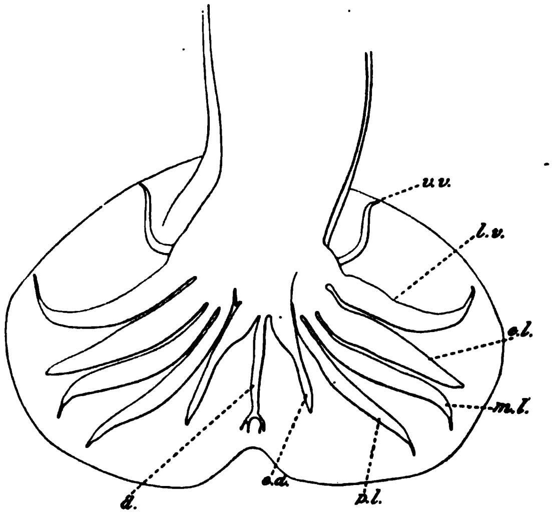


FIG. 107.—*Trichostrongylus extenuatus.* Bursa of male spread out. Dorsal view. *d.*, dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *v. v.*, ventro-ventral ray. × 300. (Original.)

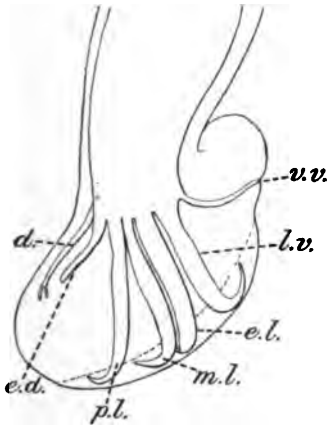


FIG. 108.—*Trichostrongylus extenuatus.* Bursa of male, viewed from right side. *d.*, dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *v. v.*, ventro-ventral ray. × 300. (Original.)

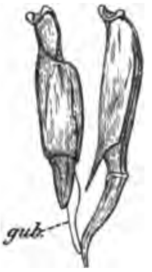


FIG. 109.—*Trichostrongylus extenuatus.* Spicules and gubernaculum of male. Ventral view. *gub.*, gubernaculum. × 300. (Original.)

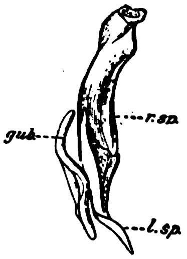


FIG. 110.—*Trichostrongylus extenuatus.* Spicules and gubernaculum of male, viewed from right side. *gub.*, gubernaculum; *l. sp.*, tip of left spicule; *r. sp.*, right spicule. × 300. (Original.)

This is a common and widely distributed parasite of ruminants in the United States. It is considered by some authors to be a cause of gastro-enteritis in calves.

### **Trichostrongylus capricola** Ransom, 1907.

(Figs. 112-117.)

1907: *Trichostrongylus capricola* Ransom, 1907k, p. 2 (from *Capra hircus* and *Ovis aries*, United States).

Specific diagnosis.—*Trichostrongylus* (p. 86): *Male* 4.3 to 4.9 mm. long by 80 to 100μ in maximum thickness a short distance in front of the bursa. The latero-ventral ray (*l. v.*, figs. 113, 114) is the longest and thickest of the rays. Next in order of thickness is the externo-lateral (*e. l.*, figs. 113,114), then the medio-lateral (*m. l.*, figs. 113, 114), then the postero-lateral ray (*p. l.*, figs. 113, 114). The ventro-ventral (*v. v.*, figs. 113, 114) and externo-dorsal (*e. d.*, figs. 113, 114) rays are the slenderest, the latter however being considerably thickened proximally and in that region equal in thickness to the postero-lateral or even the medio-lateral ray. The branches of the dorsal ray (*d.*, figs. 113, 114) are nearly equal in length to the stem, and are cleft at the end. The three lateral rays are nearly equal in length, shorter than the latero-ventral, and longer than the externo-dorsal ray. The tips of the lateral rays are separated by about equal intervals, these intervals being less than that between the tips of the postero-lateral and externo-dorsal rays, the latter interval in turn being less than that between the tips of the latero-ventral and externo-lateral rays. Spicules (figs. 115, 116) 130 to 145μ long, gubernaculum (*gub.*, figs. 115, 116) 75 to 80μ long, all three yellowish-brown in color. The distal half or two-fifths of the spicule is about half as thick as the proximal portion and forms an angle of about 140 degrees with the latter, the convexity of the spicule being dorsal. The point of the spicule, less acute than in *Trichostrongylus vitrinus*, is as in the latter without the angular projection present in *T. instabilis*.

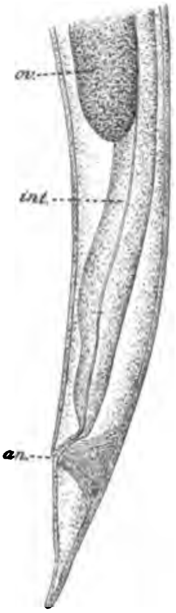


Fig. 111. — *Trichostrongylus extenuatus.* Posterior end of body of female, viewed from left side. *an.*, anus; *int.*, intestine; *ov.*, ovary. × 300. (Original.)

*Female* 5.8 to 6.8 mm. long by 75 to 80μ in maximum diameter in the region of the vulva, which is located 1.1 to 1.4 mm. from the tip of the tail. Vulva a longitudinally elongated slit, slightly diagonal in position. It is covered over by one of the lips whose edge is reflected and fused with the cuticle of the body, except at one side, where a small circular opening is left. The chitin of the lips is delicate and usually inconspicuous. Length of vulva, including lips, 45 to 50μ. The thickness of the body gradually decreases posteriorly to a size of 45 to 65μ at the level of the loop of the posterior ovary (located 140 to 230μ from the tip of the tail) and then undergoes a more rapid decrease to a size of 25 to 32μ at the anus (*an.*, fig. 117), which is situated, 60 to 80μ from the tip of the tail. The ventral outline of the tail is slightly concave immediately behind the anus, then nearly straight to the tip; the dorsal outline usually describes a slightly convex curve from the anal region to the tip. Combined length of muscular portions of ovijectors, including the sphincters, 320 to 380μ. The eggs measure 75 to 95μ in length by 35 to 45μ in width.

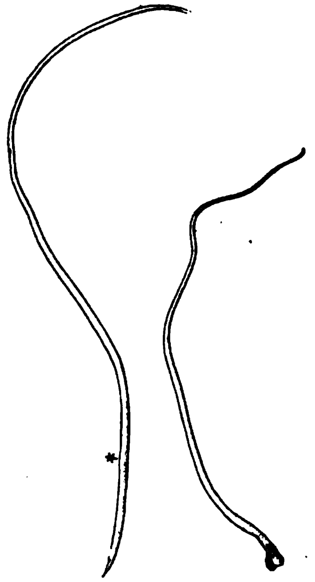


FIG. 112.—*Trichostrongylus capricola.* Male at right, female at left. * Vulva. × 15. (Original.)

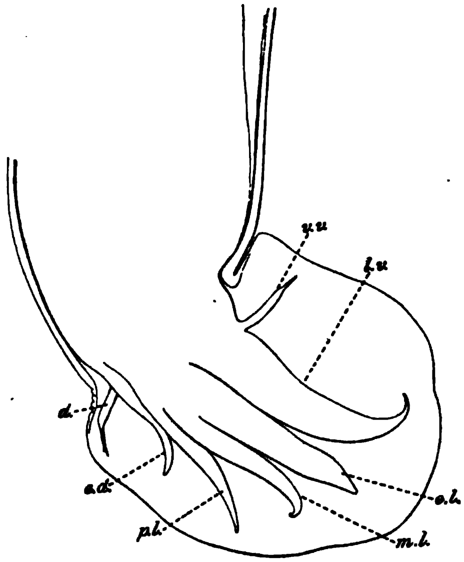


FIG. 114.—*Trichostrongylus capricola.* Bursa of male, viewed from right side. *d.*, dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *v. v.*, ventro-ventral ray. × 300. (Original.)

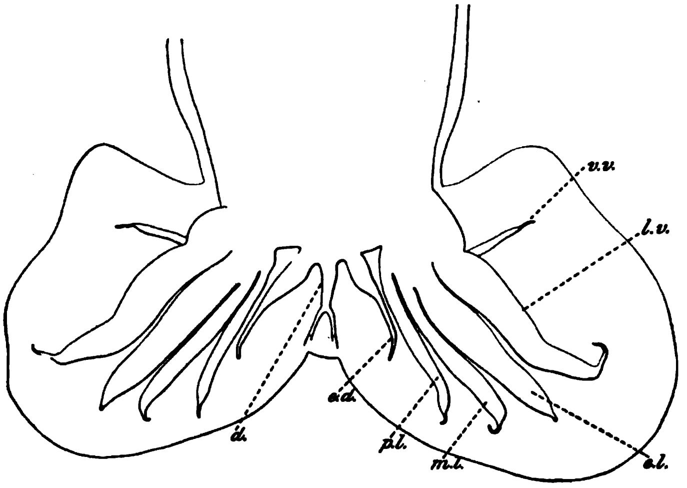


FIG. 113.—*Trichostrongylus capricola.* Bursa of male spread out *d.*, dorsal ray; *e. d.*, externo-dorsal ray; *e. l.*, externo-lateral ray; *l. v.*, latero-ventral ray; *m. l.*, medio-lateral ray; *p. l.*, postero-lateral ray; *v. v.*, ventro-ventral ray. × 300. (Original.)

HOSTS.—*Goat (*Capra hircus*); *sheep (*Ovis aries*); *prong-horned antelope (*Antilocapra americana*).

LOCATION.—Small intestine and fourth stomach.

LOCALITIES COLLECTED.—United States and Europe.

TYPE SPECIMENS.—Bureau of Animal Industry Helminthological Collection No. 14637, collected February 5, 1906, from the fourth stomach of a goat, at Bethesda, Md., by Dr. E. C. Stevenson.

This species has been frequently collected in this country from goats and sheep, more often from the former. Its presence in Europe is established by specimens in the collection of the Bureau of Animal Industry collected in France from a goat by Prof. A. Railliet.

## SPECIES OF METASTRONGYLINÆ OF UNCERTAIN POSITION.

### **Strongylus ventricosus** Rudolphi, 1809.

(Fig. 118.)

1809: *Strongylus ventricosus* Rudolphi, 1809a, pp. 222-223 (from *Cervus elaphus*, Europe).

SPECIFIC DIAGNOSIS.—Metastrongylinæ (p. 47) ? Genus: Head attenuate, with two small wings. Mouth terminal with unarmed border. Body capillary, in male increasing in size backward, in female increasing in size forward and becoming very thick and ventricose at about the beginning of the third part, then again becoming slender.

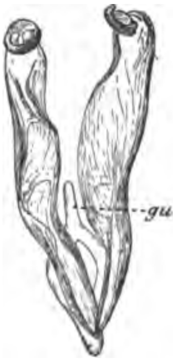


FIG. 115.—*Trichostrongylus capricola*. Spicules and gubernaculum of male. Ventral view. *gub.*, gubernaculum. × 300. (Original.)

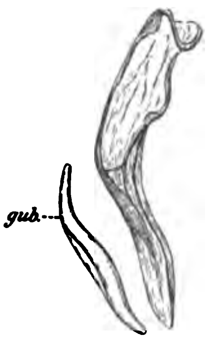


FIG. 116.—*Trichostrongylus capricola*. Spicule and gubernaculum of male. Lateral view. *gub.*, gubernaculum. × 300. (Original.)

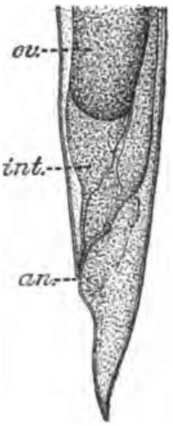


FIG. 117.—*Trichostrongylus capricola*. Posterior end of body of female, viewed from left side. *an.*, anus; *int.*, intestine; *ov.*, ovary. × 300. (Original.)

*Male* 12 to 30 mm. long by 0.1 to 0.5 mm. thick. Tail with terminal copulatory bursa deeply incised ventrally. Bursa with five rays on each side, of which the anterior one is bifid. Spicules two, with short, thick recurved shanks, slightly twisted, canaliculate.

*Female* 16 to 30 mm. long by 0.2 to 0.5 mm. thick. Tail long, acutely conical, with rather obtuse apex. Anus remote from tip of tail. Vulva in posterior part of body.

HOST.—Stag (*Cervus elaphus*).

LOCATION.—Upper small intestine.

LOCALITY COLLECTED.—Greifswald, Germany.

The foregoing description of this species is taken from Molin (1861a, p. 515), who examined 3 males and 4 females not well preserved, apparently specimens upon which Rudolphi based his description. *Strongylus ventricosus* certainly does not belong in the genus *Strongylus*. Its proper generic position can not be determined at present.

The form from cattle which Schneider (1866a, pp. 144, 145) describes as *Strongylus ventricosus* Rudolphi is distinct from that described by Molin. The former is *Cooperia oncophora* (Railliet).

### **Strongylus fordii** Daniels, 1908.

1908: *Strongylus fordii* Daniels, 1908, Studies Inst. M. Research Fed. Malay States, Singapore, v. 3, pp. 15–16 (from *Bos taurus*, East Indies).

SPECIFIC DIAGNOSIS.—Metastrongylinæ (p. 47), ? Genus: Anterior part of body for some 1 to 1.5 mm. is contracted and the cuticle somewhat thinner than elsewhere. Cervical papillæ not evident.

*Male* 19 mm. long, 0.44 mm. broad, terminates in a bilobed caudal pouch, strengthened by ribs. The spicules, which are protruded between the lobes for a variable length, are continued in the interior, are distinctly tubular, and terminate in a trumpet-shaped expansion. They are equal, and the total length is 6.2 mm., or more than one-fourth the length of the body.

*Female* 21 mm. in length, greatest breadth 0.5 mm. The mouth is terminal and the cuticle surrounding it is thickened, so as to form a circle of small rounded projections. The esophagus, 1.9 mm. in length, is thick, muscular, and ends in a slight dilation before the marked junction with the intestine. Anus close to the sharp-pointed tail. Ovarian tubes double, not twisted round the intestine as in *Hæmonchus contortus*, and end in a long thin-walled vagina, in which a single row of eggs is contained. The genital opening is marked by no protecting fold and is situated 0.5 to 0.6 mm. from the tip of the tail.

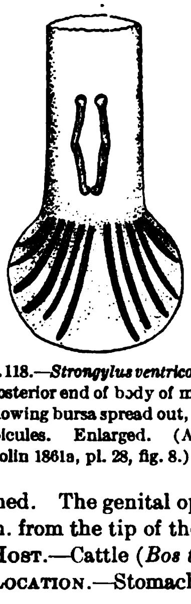


FIG. 118.—*Strongylus ventricosus*. Posterior end of body of male, showing bursa spread out, and spicules. Enlarged. (After Molin 1861a, pl. 28, fig. 8.)

HOST.—Cattle (*Bos taurus*).

LOCATION.—Stomach or intestine.

LOCALITY COLLECTED.—East Indies.

The description given by Daniels, on which the foregoing diagnosis is based, is too imperfect to properly place this species generically. It evidently, however, does not belong in the genus *Strongylus*.

## FAMILY FILARIIDÆ CLAUS, 1885.

FAMILY DIAGNOSIS.—Nematoda: Body long, filiform. Mouth surrounded with papillæ, or provided with two lips. Esophagus slender, without posterior bulb. Males with a single spicule or with two unequal spicules. Females with two ovaries; vulva usually in front of the middle of the body. Usually ovo-viviparous. Development in many cases requires an intermediate host.

TYPE GENUS.—*Filaria* Müller, 1787.

Two genera of this family are represented among the nematodes parasitic in the alimentary tract of ruminants.

### KEY TO GENERA OF FILARIIDÆ.

Anterior portion of body covered with numerous cuticular tubercles or shields; vulva of female in posterior portion of body, a short distance in front of anus; male 30 to 50 mm. long, female 70 to 145 mm. long................*Gongylonema*, p. 100

Anterior portion of body without cuticular tubercles; vulva of female in anterior portion of body; male 9 to 13 mm. long, female 12 to 26 mm. long. *Spiroptera*, p. 103

## Genus GONGYLONEMA Molin, 1857.

1857: *Gongylonema* Molin, 1857a, pp. 148-152, 216-223.

1892: *Myzomimus* Stiles, 1892b, pp. 65-67 (type species, *M. scutatus* (Mueller, 1869) Stiles, 1892).

Generic diagnosis.—Filariidæ (p. 99): Body filiform, slightly attenuated toward the two extremities. Cuticle transversely striated. Mouth small, elongated dorsoventrally, surrounded by six small papillæ. Anterior portion of body covered with numerous tubercles or shields formed by differentiation of the cuticle. In the median lines immediately behind the mouth, two semilunar depressions simulating suckers, one dorsal and one ventral. A short distance behind the mouth two cervical papillæ, one in each lateral line. Esophagus consists of two distinct portions, a slender anterior portion, and a thicker posterior portion. Tail of male curved ventrally, supplied with two asymmetrical membranous wings, supported by elongated, claviform papillæ, mostly arranged in pairs, some preanal and some postanal. Two unequal spicules, one short, one very long. Vulva of female situated a short distance in front of anus. Eggs ellipsoidal, containing vermiform embryos when deposited.

Type species.—*Gongylonema minimum* Molin, 1857.

Two species of this genus are found in the alimentary tract of ruminants.

### KEY TO SPECIES OF GONGYLONEMA.

A membranous wing along the dorsal median line in the anterior portion of the body; cuticular tubercles lacking on ventral surface of female; tail of female suddenly diminished in size behind the anus; male 35 to 40 mm. long, female 70 to 90 mm. long....................................*Gongylonema verrucosum*, p. 102

Dorsal median line without longitudinal membranous wing; cuticular tubercles present on ventral surface of female; tail of female gradually diminished in size behind the anus; male 30 to 50 mm. long, female 80 to 145 mm. long. *Gongylonema scutatum*, p. 100

## **Gongylonema scutatum** (Mueller, 1869) Railliet, 1892.

(Figs. 119-122.)

1869: *Spiroptera scutata* F. Mueller, 1869a, pp. 127-129.

1873: *Filaria scutata* Leuckart, 1873b, p. 557.

1892: *Myzomimus scutatus* (Mueller) Stiles, 1892b, pp. 65-67, 1 fig.

1892: *Gongylonema scutatum* (Mueller) Railliet, 1892e, pp. 694-696.

Specific diagnosis.—*Gongylonema* (p. 100): Cuticular tubercles present in the anterior 1 to 3 mm. of the body, rounded or oval, arranged more or less regularly in two rows in each of the four submedian fields (fig. 119). On the ventral surface surrounding the excretory pore, some of the tubercles of the four ventral rows are commonly fused into a single plate. Along each lateral line, behind the cervical papillæ, a membranous wing which terminates at about the posterior limits of the cuticular tubercles. Mouth oblong, with two lateral and four smaller submedian papillæ.

*Male* 30 to 50 mm. long by about $250\mu$ thick. Tail (figs. 121, 122) slightly twisted on its axis, as a result of the arrangement of the asymmetrical bursal wings. The right wing is nearly parallel to the median plane of the body, widest at a point a little behind the level of the anus, terminating slightly in front of the tip of the tail toward its dorsal surface. A supplementary wing begins on the right side on the dorsal surface near the tip of the tail, and passes around the latter. The left wing follows a slightly twisted course, beginning on the dorsal surface and extends to the tip of the tail which it surrounds. The left wing is shorter than the right and its maximum width is less. On its inner surface in its posterior portion there are frequently found supplementary lobes with undulating borders. Each wing is supported by 5 or 6 preanal papillæ and 5 to 7 postanal papillæ, usually asymmetrical in arrangement. Left spicule 16 to 17 mm. long; right spicule 140 to $180\mu$ long.

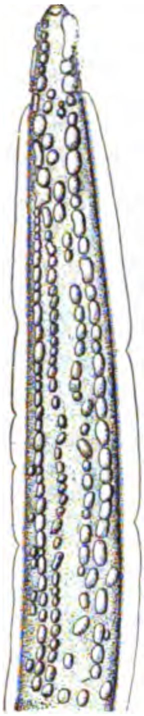


FIG. 119.—*Gongylonema scutatum.* Anterior end of body. Dorsal view. × 45. (After Neumann, 1894d., fig. 1.)

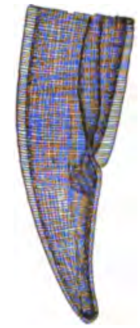


FIG. 120.—*Gongylonema scutatum.* Posterior end of body of female, viewed from right side. × 65. (After Neumann, 1894d., fig. 2—1.)

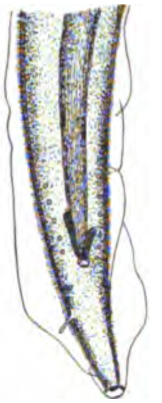


FIG. 121.—*Gongylonema scutatum.* Posterior end of body of male. Ventral view. × 65. (After Neumann, 1894d., fig. 2—2.)

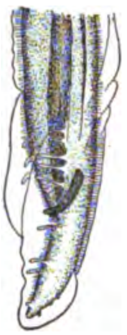


FIG. 122.—*Gongylonema scutatum.* Posterior end of body of male, viewed obliquely from left side. × 65. (After Neumann, 1894d., fig. 2—2g.)

*Female* 80 to 145 mm. long by 300 to $350\mu$ thick. Vulva 4 to 5 mm. from the tip of the tail. Eggs 55 to $60\mu$ long by 32 to $36\mu$ wide. Embryos provided with a buccal stylet.

HOSTS.—*Cattle (*Bos taurus*); *sheep (*Ovis aries*); goat (*Capra hircus*); zebu (*Bos indicus*).

LOCATION.—In burrows in the lining mucosa of the esophagus and pharynx, occasionally free in the lumen of the paunch.

LOCALITIES COLLECTED.—Europe, United States, India, North Africa, Australia.

This is a very common species in this country and is seen in a large percentage of cattle and sheep slaughtered at abattoirs. It has been frequently observed in Europe and Africa, and probably is distributed throughout most of the world. It has been reported from a horse by Müller (1869a). *Gongylonema scutatum* has no apparent effect on the health of animals which it infests. Its only economic importance so far as recognized is in rendering the esophagus undesirable for use in meat food products.

### **Gongylonema verrucosum** (Giles, 1892) Neumann, 1894.

(Figs. 123-125.)

1892: *Trichosomum verrucosum* Giles, 1892d, pp. 47-48.

1892: *Spiroptera verrucosa* Giles, 1892d, Addendum (not *Spiroptera verrucosa* Molin, 1860).

1894: *Gongylonema verrucosum* (Giles) Neumann, 1894d, pp. 470-472, fig. 4.

1898: *Gongylonema crenatum* Railliet, 1898b, p. 173 (*G. verrucosum* renamed).

SPECIFIC DIAGNOSIS.—*Gongylonema* (p. 100): Cuticular tubercles, large, rather widely separated, striated transversely, lacking on the ventral surface in the female, forming two or three irregular longitudinal rows 3 mm. long on each side of the median line on the dorsal surface (fig. 123). In the anterior portion of the body a narrow festooned membranous wing along each lateral line, and a deeply and regularly festooned wing along the dorsal median line. Cervical papillæ small. Mouth surrounded by six papillæ.

*Male* 35 to 40 mm. long by 250 to 300$\mu$ thick. Five or six pairs of preanal and five pairs of postanal papillæ (fig. 124). Right bursal wing shorter and much narrower than the left, terminating posteriorly some distance from the tip of the tail, where it is replaced by a supplementary wing, dorsal in origin. Left bursal wing wide and prolonged to the tip of the tail. Left spicule about 10 mm. long; right spicule about 300$\mu$ long.

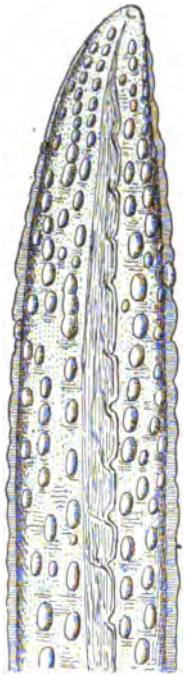


FIG. 123.—*Gongylonema verrucosum*. Anterior end of body. Dorsal view. × 57. (After Neumann, 1894d, fig. 4—1.)

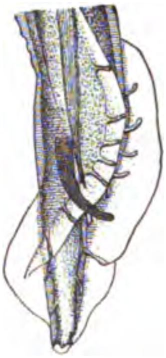


FIG. 124.—*Gongylonema verrucosum*. Posterior end of body of male, viewed obliquely. × 65. (After Neumann, 1894d, fig. 4—2.)

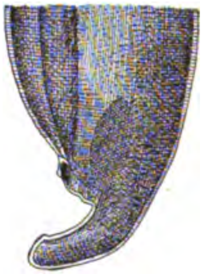


FIG. 125.—*Gongylonema verrucosum*. Posterior end of body of female, viewed from left side. × 60. (After Neumann, 1894d, fig. 4—3.)

*Female* 70 to 90 mm. long by 420 to 460$\mu$ in thickness. Vulva 1.2 mm. to 3.2 mm. from the tip of the tail. Behind the anus the tail (fig. 125) is abruptly diminished in thickness, forming a terminal appendage 0.2 mm. long, provided with a median ventral papilla. Eggs 45 to 50$\mu$ long by 25 to 27$\mu$ wide.

HOSTS.—Zebu (*Bos indicus*); sheep (*Ovis aries*).

LOCATION.—Stomach, free in the lumen or in galleries which the parasite burrows in the mucosa.

LOCALITY COLLECTED.—India.

This species has not yet been reported from the United States. The foregoing diagnosis is based on Neumann's (1894d) description.

### Genus SPIROPTERA Rudolphi, 1819.

1811: *Acuaria* Bremser, 1811a, p. 26 (type species, *Spiroptera anthuris*, established by Rudolphi 1819a, p. 244).
1819: *Spiroptera* Rudolphi, 1819a, pp. 22-29, 235-255 (*Acuaria* renamed).
1819: *Anthuris* Rudolphi, 1819a, p. 244 (*Acuaria* renamed).
1845: *Dispharagus* Dujardin, 1845a, pp. 42, 69-82 (type species, *Spiroptera anthuris*).

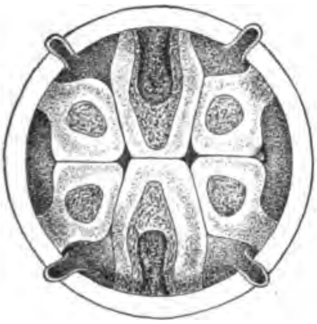


FIG. 126.—*Spiroptera verrucosa*. Head. Anterior view. × 280. (After Drasche, 1884a, pl. 11, fig. 18.)

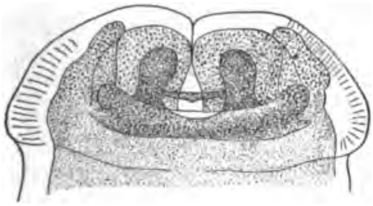


FIG. 127.—*Spiroptera verrucosa*. Head. Median view. × 280. (After Drasche, 1884a, pl. 11, fig. 19.)

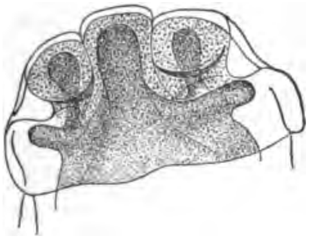


FIG. 128.—*Spiroptera verrucosa*. Head. Lateral view. × 280. (After Drasche, 1884a, pl. 11, fig. 20.)

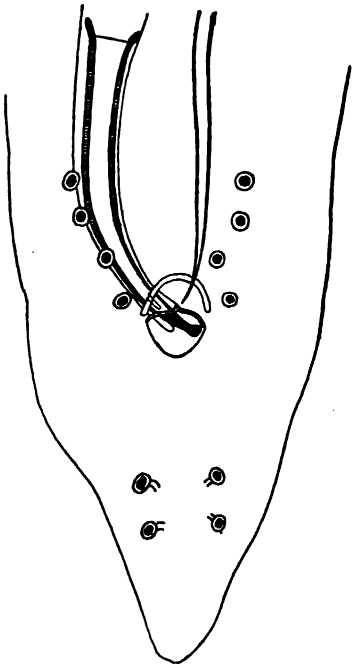


FIG. 129.—*Spiroptera verrucosa*. Posterior end of body of male. Ventral view. × 120. (After Drasche, 1884a, pl. 13, fig. 1.)

*Spiroptera* (or more properly *Acuaria*) is commonly included in the family Filariidæ. As it is probable that *Spiroptera verrucosa* (the only species of the genus to be considered in the present paper) does not belong in the genus *Spiroptera*, and as the characters of the genus are very imperfectly known, I have not attempted to formulate a generic diagnosis.

The name *Spiroptera* is an absolute synonym of the earlier *Acuaria*, but I have retained the former name in the present paper in order to avoid adding to the synonymy of *Spiroptera verrucosa*.

### KEY TO SPECIES OF SPIROPTERA.

One species in ruminants............................ *Spiroptera verrucosa*, p. 104

### Spiroptera verrucosa Molin, 1860.

(Figs. 126–129.)

1860: *Spiroptera verrucosa* Molin, 1860b, pp. 964–965 (from *Cervus nambi* [=*Mazama nana*] and *Cervus dichotomus* [=*Blastocerus paludosus*], Brazil).
1897: *Filaria verrucosa* (Molin, 1860) Stossich, 1897b, pp. 53–54 (*S. verrucosa* Molin, renamed).

SPECIFIC DIAGNOSIS.—*Spiroptera* (p. 103): Anterior end of body scarcely attenuated with rotund apex. Head (figs. 126–128) distinct from rest of body, provided with two large lateral lips, each of which is subdivided into three parts by two deep furrows. The lips meet in a straight dorso-ventral median line. Four large conical submedian papillæ at the base of the lips. Cuticle of body densely striated transversely. Two longitudinal lateral wings.

*Male* 9 to 13 mm. long by 0.3 mm. thick. Tail (fig. 129) obtusely pointed, curled spirally in one or two turns, with conspicuous lateral wings. Four pairs of large preanal papillæ and two pairs of postanal papillæ. A semilunar thickening of the cuticle in front of the anus. Right spicule thick, curved, blunt, about 375$\mu$ long; left spicule filiform, acutely pointed, alate, and about five times as long as the right.

*Female* 12 to 26 mm. long by 0.4 to 0.6 mm. thick. Tail curved, with obtuse apex. Anus not far from the tip of the tail. Vulva in anterior portion of body.

HOSTS.—Pygmy brocket (*Mazama nana*); marsh deer (*Blastocerus paludosus*).

LOCATION.—Stomach.

LOCALITY COLLECTED.—Brazil.

The foregoing diagnosis is based upon the original description by Molin (1860b) and the description and figures given by Drasche (1884a, p. 203, pl. 11, figs. 18–20, pl. 13, fig. 1), who reexamined Molin's specimens.

## FAMILY ANGIOSTOMIDÆ Braun, 1895.

FAMILY DIAGNOSIS.—Nematoda: Two heterogenetic generations, one of free-living males and females and one of hermaphroditic or parthenogenetic forms, which are parasitic.

TYPE GENUS.—*Angiostoma* Dujardin, 1845.

### KEY TO GENERA OF ANGIOSTOMIDÆ.

One genus in ruminants........................................ *Strongyloides*, p. 104

### Genus STRONGYLOIDES Grassi, 1879.

1879: *Strongyloides* Grassi, 1879f, p. 497.
1879: *Stronglodes* Grassi, 1879e, p. 233.
1881: *Pseudo-rhabditis* Perroncito, 1881w, pp. 499–519.

GENERIC DIAGNOSIS.—Angiostomidæ (p. 104): Parasitic form with mouth opening directly into the relatively very long subcylindrical esophagus. Mouth surrounded by (?six) small papillæ. Cuticle finely striated transversely. Vulva posterior of the middle of the body. Uterus double. Two ovaries. Eggs ellipsoidal with thin shells. Free-living form with mouth opening into a vestibule or pharynx, followed by an esophagus whose anterior portion is fusiform and posterior portion globular. The posterior bulb of the esophagus of the free-living form is furnished with a toothed masticatory apparatus. Free-living male with two short spicules of equal size.

TYPE SPECIES.—*Strongyloides intestinalis* (Bavay, 1877) Grassi, 1879=*S. stercoralis* (Bavay, 1876).

Two species of this genus are found in ruminants.

### KEY TO SPECIES OF STRONGYLOIDES.

Anus 55 to 70$\mu$ from the tip of the tail; eggs deposited singly, not inclosed in sacs. *Strongyloides papillosus*, p. 105

Anus 45 to 50$\mu$ from the tip of the tail; eggs after passing out of the vulva lodge beneath an outer cuticular layer, which when shed by the worm forms egg-sacs, each containing from half a dozen to 50 or more eggs. .*Strongyloides ovocinctus*, p. 108

### **Strongyloides papillosus** (Wedl, 1856), Ransom, 1911.

(Figs. 130-133.)

1856: *Trichosoma papillosum* Wedl, 1856b, pp. 129–130, figs. 13–14.
1887: *Rhabdonema longus* Grassi and Segrè, 1887a, p. 107.
1888: *Strongyloides longus* (Grassi and Segrè) Rovelli, 1888.
1911: *Strongyloides papillosus* (Wedl) Ransom, 1911, pp. 15, 105–108, 109, 110, 121, 122, figs. 130–133 (the present paper).

SPECIFIC DIAGNOSIS.—*Strongyloides* (p. 104): *Parasitic generation.* Length 3.5 to 6 mm., thickness 50 to 60$\mu$. Body (fig. 130) filiform, of nearly equal thickness throughout most of its length, gradually attenuated anteriorly to a diameter of about 15$\mu$ at the head. Posterior end of body (fig. 132) diminished in size backward beginning some distance in front of the anus near the loop of the posterior ovary (*ov.*, fig. 132), then suddenly reduced just behind the anus, and terminating in a short slightly tapering tail with rounded tip. Esophagus increases gradually in size posteriorly, and is 650 to 800$\mu$ long. Diameter of body at base of esophagus 40 to 45$\mu$. Anus (*an.*, fig. 132) 55 to 70$\mu$ from the tip of the tail. Diameter of body at anus about 20$\mu$. Vulva (*vul.*, fig. 131) a transverse slit with rather salient lips situated 1.6 to 2 mm. from the posterior end of the body. Eggs (*e.*, fig. 131) ellipsoidal with very thin shells, 40 by 20$\mu$ to 60 by 25$\mu$ in diameter. Not more than a dozen or fifteen fully formed eggs present in the two uteri at any one time. Eggs of this species when passed in the feces of the host usually contain vermiform embryos which hatch in a few hours under suitable conditions of temperature.

*Free-living generation.* *Male* undescribed. *Female* (fig. 133) 1 to 1.2 mm. long by 40$\mu$ in thickness. Esophagus $\frac{1}{10}$ to $\frac{1}{4}$ the total length of the body. Vulva (*vul.*, fig. 133) with salient lips near the middle of the body. Tail slender, acutely pointed. Anus (*an.*, fig. 133) about $\frac{1}{10}$ the length of the body from the posterior end. Eggs (*e.*, fig. 133) 65 by 30$\mu$ in diameter.

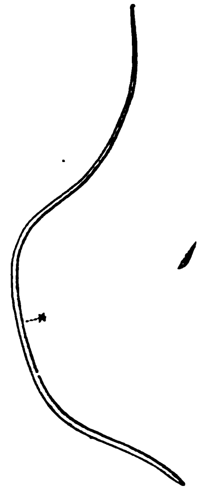
HOSTS.—*Sheep (*Ovis aries*); *goat (*Capra hircus*); *rabbit (*Lepus cuniculus*); also reported from other rodents.

LOCATION.—Small intestine.

LOCALITIES COLLECTED.—Europe, United States, ? South America.

Wedl (1856b) found in the intestine of a sheep rather numerous specimens of hair-like worms which he described under the name of *Trichosoma papillosum.* He remarks that only females were present. His description translated is as follows:

Length 5 mm. Anterior portion of body attenuated, head 16$\mu$ broad. In posterior portion of body the breadth increases to 55$\mu$. Tail terminating in a bluntly pointed



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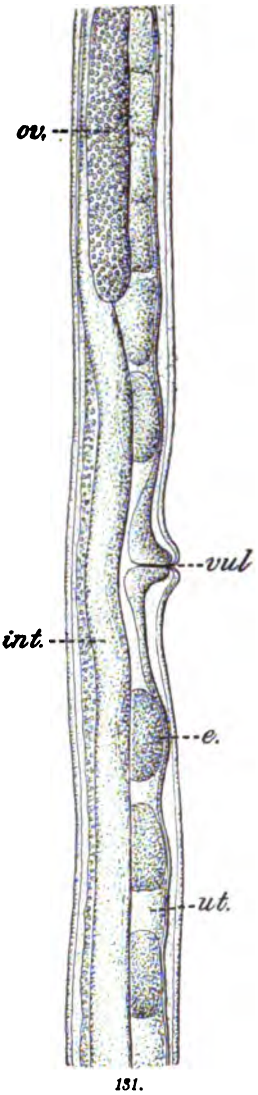

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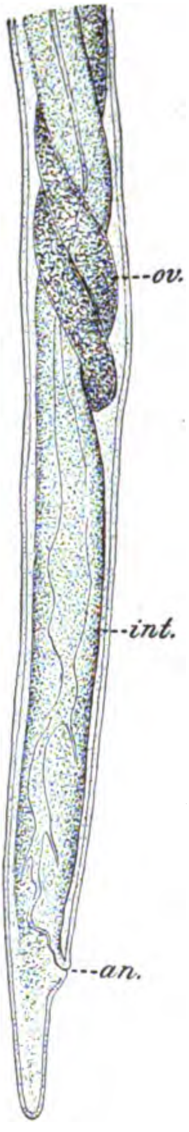

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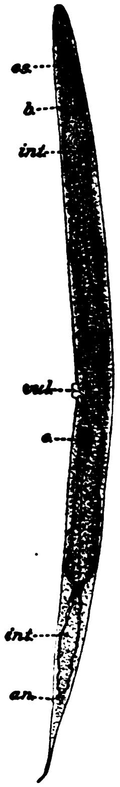

133.

FIG. 130.—*Strongyloides papillosus.* Parasitic adult. * Vulva. × 15. (Original.)

FIG. 131.—*Strongyloides papillosus.* Portion of body of parasitic adult in region of vulva, viewed from right side. *e.*, egg; *int.*, intestine; *ov.*, ovary; *ut.*, uterus; *vul.*, vulva. × 300. (Original.)

FIG. 132.—*Strongyloides papillosus.* Posterior end of body of parasitic adult, viewed from right side. *an.*, anus; *int.*, intestine; *ov.*, ovary. × 300. (Original.)

FIG. 133.—*Strongyloides papillosus.* Female of free-living generation, viewed from left side. *an.*, anus; *b.*, posterior bulb of esophagus; *e.*, egg in uterus; *es.*, esophagus; *int.*, intestine; *vul.*, vulva. × 100. (Original.)

conical tip. Head supplied with 4 well marked papillæ. Esophagus very long, presenting a well marked line which indicates its lumen. The relatively large vulva is situated at the beginning of the posterior third of the body, its position indicated by a slightly projecting papilla. Uterus bicornate, not infrequently evaginated through the vulva. Eggs arranged in uterus in a single row, or may be shoved together so that one lies over another. Eggs ellipsoidal, thin-shelled, 48 to 52μ long by 28μ broad. Ovaries much twisted, wound spirally around the intestine.

Curtice (1890c) was of the opinion that *Trichosoma papillosum* should be united with *Strongylus filicollis* (= *Nematodirus filicollis*), remarking that Wedl's species was certainly not a trichosome since it possesses a double uterus. Railliet (1893a, p. 489) notes that the difference in the size of the eggs precludes the possibility of *Trichosoma papillosum* and *Strongylus filicollis* being the same, and he considers Wedl's species to be a strongyle.

Wedl's description and figures correspond perfectly, however, with *Strongyloides longus* (Grassi and Segrè) and there can be little doubt that *Trichosoma papillosum* and *Strongyloides longus* are one and the same species, which under the rules of nomenclature takes the name *Strongyloides papillosus.*

*Strongyloides papillosus* is an interesting example of a nematode in whose life-cycle there may be two generations of dissimilar individuals, one generation parasitic and the other free-living. The parasitic generation consists entirely of parthenogenetic females, from whose eggs hatch embryos which may either develop into free-living males and females or transform into filariform larvæ. As pointed out in a former paper (Ransom, 1907k) the latter develop into the parthenogenetic parasitic forms if taken into the body of a suitable host, infection occurring either by way of the mouth or through the skin, which the larvæ may penetrate and finally reach the intestine, presumably following a course similar to that taken by larval hook-worms when they enter the body through the skin, that is, by way of the blood vessels, heart, lungs, trachea, pharynx, esophagus, and stomach.

In the event of the development of embryos produced by the parthenogenetic forms into free-living adults it has been found, as in the case of *Strongyloides stercoralis,* that from these come embryos which transform into filariform larvæ resembling those which develop directly from the parasitic generation. The life-cycle may therefore include in the following order, first, parthenogenetic parasitic forms; second, free-living rhabditiform embryos (newly hatched embryos whose esophagus is swollen posteriorly into a bulb containing a masticatory apparatus); and, third, free-living filariform larvæ (with esophagus similar to the parasitic adult); or, first, parthenogenetic parasitic forms; second, free-living rhabditiform embryos; third, free-living males and females, from which come free-living rhabditiform embryos and these in turn transform into free-living filariform larvæ, the filariform larvæ in both cases developing into the parasitic parthenogenetic adults when taken into the body of a suitable host.

*Strongyloides papillosus* may occur in sheep in enormous numbers, but it is questionable whether it has any serious effects upon the health of infested animals. On superficial examination this parasite is likely to be confused with the females of a species already considered, *Trichostrongylus extenuatus*. It has been commonly met with in sheep and goats at the Bureau of Animal Industry Experiment Station, Bethesda, Md., and has been reared experimentally (Ransom, 1907k) in rabbits by feeding larvæ and by placing larvæ on the skin. It has been recorded by different observers as a parasite of sheep and rabbits in Europe. The parasite of the pig which has been identified as *Strongyloides longus* (=*S. papillosus*) by European observers is probably *Strongyloides suis*. This species has been found a number of times in pigs at the Bureau of Animal Industry Experiment Station, Bethesda, Md.

### Strongyloides ovocinctus Ransom, 1911.

(Figs. 134-137.)

1911: *Strongyloides ovocinctus*, Ransom 1911, pp. 15, 18, 23, 105, 108–110, 112, 122, figs. 134–137 (the present paper).

SPECIFIC DIAGNOSIS.—*Strongyloides* (p. 104): *Parasitic generation*. Length 4.5 to 5 mm., thickness 40 to 50μ. Body (fig. 134) filiform of nearly equal thickness throughout its length, gradually attenuated anteriorly to a diameter of about 15μ at the head. Posterior end of body diminished in size backward, beginning some distance in front of the anus near the loop of the posterior ovary, then suddenly reduced just behind the anus, and terminating in a short, slightly tapering tail with rounded tip (fig. 136). Esophagus increases in size posteriorly, 600 to 750μ long. Diameter of body at base of esophagus 40 to 45μ. Anus (*an.*, fig. 136) 45 to 50μ from the tip of the tail. Diameter of body at anus about 20μ. Vulva (*vul.*, fig. 135) a transverse slit with rather salient lips, situated 1.6 to 2 mm. from the tip of the tail. Eggs (*e.*, figs. 135, 136) ellipsoidal with very thin shells, 45 by 30μ to 50 by 25μ in diameter. Not over 25 fully formed eggs in the two uteri at any one time. Adult worms apparently undergo successive molts. The eggs passing out of the vulva lodge beneath an outer cuticular layer (*cut.*, figs. 135, 136), which when finally shed by the worm is transformed into elongated egg sacs (fig. 137), each containing from half a dozen to 50 or more eggs.

*Free-living generation*. Unknown.

HOST.—*Prong-horned antelope (*Antilocapra americana*).

LOCATION.—Intestine.

LOCALITY COLLECTED.—United States.

TYPE SPECIMENS.—Bureau of Animal Industry Helminthological Collection No. 1947, collected August 13, 1892, at Washington, D. C., by Dr. Albert Hassall.

Were it not for the remarkable manner in which *Strongyloides ovocinctus* deposits its eggs this species could be scarcely distinguished from *Strongyloides papillosus*. Both species are of practically the same size; the general form of the body is the same in both; the esophagus is of similar shape and size; the vulva is located in the same region of the body; and the tail has the same shape in both species. In *S. papillosus* the tail is generally somewhat longer than has been noted in *S. ovocinctus*, 55 to 70μ as compared with 45 to 50μ. The eggs also appear to average larger, 40 to 60μ in length in the former, as compared with 45 to 50μ in the latter. Another difference is in the maximum number of fully formed eggs which may be present in the uteri, not more than 15 having been observed in *S. papillosus*, whereas in *S. ovocinctus* as many as 25 have been counted. These differences, however, are of minor importance in view of the possibility that an examination of a large number of specimens of both species would demonstrate the occurrence of individual variations with a range wide enough to obliterate the apparent differences just enumerated. Hence the only important differences thus far recog-

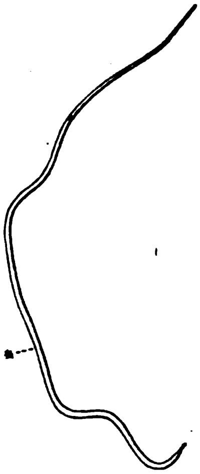

FIG. 134.—*Strongyloides ovocinctus.* Parasitic adult. * Vulva. × 15. (Original.)

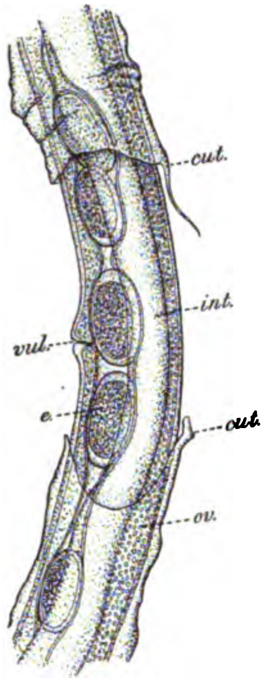

FIG. 135.—*Strongyloides ovocinctus.* Portion of body of parasitic adult in region of vulva, viewed from left side. *cut.*, outer cuticular layer; *e.*, egg; *int.*, intestine; *ov.*, ovary; *vul.*, vulva. × 300. (Original.)

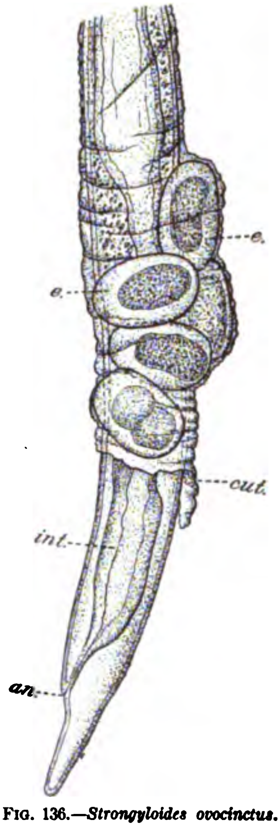

FIG. 136.—*Strongyloides ovocinctus.* Posterior end of body of parasitic adult, viewed from left side. *an.*, anus; *cut.*, outer cuticular layer; *e.*, eggs lodged beneath the outer loosened cuticle; *int.*, intestine. × 300. (Original.)

nized in the two species is in the method of oviposition, and even here the possibility is not excluded that this is only an apparent and not a real difference, and that it is simply due to an imperfect knowledge of *S. papillosus*. However, I have examined a considerable number of specimens of *S. papillosus* without finding any evidence of the occurrence of the peculiar method of oviposition characteristic of *S. ovocinctus*, and it therefore seems advisable for the present to recognize two distinct species.

It should be noted as of interest in the present connection that Brumpt (1910, Précis de parasitologie, p. 431, fig. 270) has mentioned the occurrence of strings of *Strongyloides* eggs in the feces of sheep. He interprets the sheath surrounding the string of eggs as the body of a dead worm or its uterus. Evidently these strings of eggs are the result of a process of oviposition similar to that occurring in *Strongyloides ovocinctus*. Whether the *Strongyloides* in question was *S. ovocinctus*, *S. papillosus*, or another species is uncertain. Looss (1905, Handbuch d. Tropenkrankh. [Mense], v. 1, p. 189) states with reference to *S. stercoralis* that this species, which normally deposits its eggs in the burrows which it forms in the intestinal mucosa, may when wandering free in the lumen of the intestine deposit its eggs in short strings. Looss, however, gives no description of these strings or eggs, nor does he offer an explanation of the way in which they are formed. It is very probable that the strings of eggs deposited by *S. stercoralis* originate in the same manner as those deposited by *S. ovocinctus*, and hence it seems not unlikely that the process of oviposition which occurs in *S. ovocinctus* will be found on further investigation to be of general occurrence in the genus *Strongyloides*.

## FAMILY TRICHINELLIDÆ STILES and CRANE, 1910.

FAMILY DIAGNOSIS.—Nematoda: Esophagus consisting of a chain of single cells, the lumen of the esophagus passing through the center of each cell. Anterior portion of body, occupied by esophagus, usually very slender; posterior portion occupied by intestine and reproductive organs, more or less swollen. Spicule of male single or absent. One testicle. Only one ovary. Vulva situated at the junction of the anterior and posterior portions of the body.

TYPE GENUS.—*Trichinella* Railliet, 1895.

Two subfamilies may be recognized in this family.

### KEY TO SUBFAMILIES OF TRICHINELLIDÆ.

| | |
|---|---|
| Male with spicule | Trichurinæ, p. 111 |
| Male without spicule; only accidental in ruminants | Trichinellinæ, p. 120 |

### Subfamily TRICHURINÆ Ransom, 1911.

SUBFAMILY DIAGNOSIS.—Trichinellidæ (p. 110): Male with spicule. Female deposits eggs characterized by the presence of an opening at each pole closed by a plug-like operculum. Development so far as known direct, without intermediate host, and without encysted larval stage. Eggs do not hatch until after they have been swallowed by a suitable host.

TYPE GENUS.—*Trichuris* Roederer and Wagler, 1761.

Two genera of this subfamily are represented among the nematodes of ruminants.

#### KEY TO GENERA OF TRICHURINÆ.

Anterior portion, or esophageal region, of body very slender, and considerably longer than the posterior portion which is much thicker and contains the reproductive organs; males 40 to 80 mm. long, females 48 to 70 mm. long ..... *Trichuris*, p. 111

Posterior portion of body less than one-tenth of a millimeter in diameter; not much thicker than the anterior portion; anterior portion of body not as long as the posterior portion; males 8 to 13 mm. long, females 12 to 20 mm. long. *Capillaria*, p. 117

### Genus TRICHURIS Roederer and Wagler, 1761.

1761: *Trichuris* Roederer and Wagler in Roederer, 1761a, p. 243.
1782: *Trichocephalos* Goeze, 1782a, pp. 40, 112–123 (*Trichuris* renamed).
1788: *Trichocephalus* Schrank, 1788a, pp. 4–5.
1800: *Mastigodes* Zeder, 1800a, pp. 5–6 (*Trichuris* renamed).
1801: *Tricocephalus* Lamarck, 1801a, p. 338.

GENERIC DIAGNOSIS.—Trichurinæ (p. 111): Anterior portion or esophageal region of body, very long and slender; posterior portion of body containing the intestine and reproductive organs relatively thick and much shorter than the anterior portion. Posterior extremity of body blunt and rounded. Anus terminal or nearly terminal. On the ventral surface of the anterior portion of the body a broad longitudinal band (bacillary band) formed by a mass of punctiform projections, which are the points of small rod-like structures emanating from subcuticular cells and penetrating the cuticle. This bacillary band terminates near the beginning of the thick posterior portion of the body. Cuticle with annular striations whose posterior edges project slightly, giving a finely serrate appearance to the contour of the body. Annular striations of the cuticle absent from the ventral surface of the anterior portion of the body, stopping at the edges of the bacillary band.

*Male.* Posterior portion of body rolled dorsally into a spiral. Spicule surrounded by a prepuce-like sheath which evaginates when the spicule is protruded. External surface of the evaginated sheath smooth, or provided with little spines.

*Female.* Posterior portion of body may be slightly curved, but not rolled into a spiral. Vulva near the beginning of the thick posterior portion of the body. Shell of egg thick, usually brown in color, with an opening at each pole closed by a plug-like operculum. Eggs ellipsoidal.

TYPE SPECIES.—*Trichuris trichiura* (Linnæus, 1767).

Six species of *Trichuris*, two of them very imperfectly known, occur in ruminants.

#### KEY TO SPECIES OF TRICHURIS.

(The very imperfectly known species *Trichuris cameli*, p. 116, and *T. giraffæ*, p. 117, are not included in this key.)

1. Spicule less than 2 mm. long ............................ *Trichuris discolor*, p. 114
   Spicule more than 2 mm. long.................................................. 2

2. Sheath of spicule, when evaginated, without bulbous enlargement at end; armed with 20 longitudinal rows of conical spines; spicule 3 mm. long by 8$\mu$ thick. *Trichuris alcocki*, p. 115

Sheath of spicule, when evaginated, with bulbous enlargement at end......... 3

3. Spines on bulbous enlargement of spicule sheath more than twice as long as the spines on the rest of the sheath; spicule 4.3 mm. long... *Trichuris globulosa*, p. 115

Spines on bulbous enlargement of spicule sheath not longer than the spines on the rest of the sheath; spicule 5 to 6 mm. or more in length..... *Trichuris ovis*, p. 112

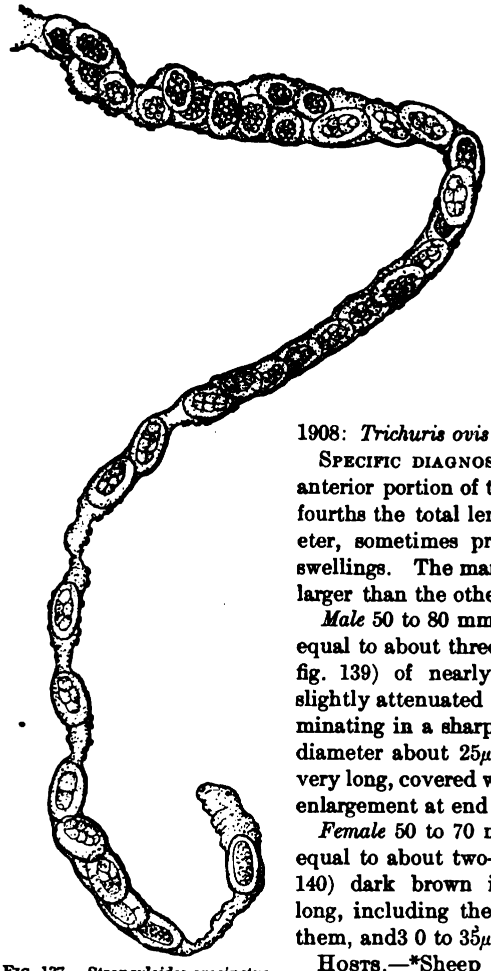

FIG. 137.—*Strongyloides ovocinctus.* Egg-string. × 150. (Original.)

### **Trichuris ovis** (Abildgaard, 1795) Smith, 1908.

(Figs. 138-140.)

1795: *Trichocephalus ovis* Abildgaard, 1795 (on the authority of Railliet, 1893a, p. 481).

1802: *Trichocephalus affinis* Rudolphi, 1802a, p. 7.

1803: *Mastigodes affinis* (Rudolphi) Zeder, 1803a, p. 70.

1908: *Trichuris ovis* (Abildgaard) Smith, 1908a, p. 269.

SPECIFIC DIAGNOSIS.—*Trichuris* (p. 111): The slender anterior portion of the body equals two-thirds to three-fourths the total length. Head less than 10$\mu$ in diameter, sometimes provided with two lateral vesicular swellings. The marginal rods of the bacillary band are larger than the others.

*Male* 50 to 80 mm. long; anterior portion of the body equal to about three-fourths the length. Spicule (*sp.*, fig. 139) of nearly equal thickness throughout, but slightly attenuated from in front posteriorly and terminating in a sharp point; length 5 to 6 mm. or more; diameter about 25$\mu$. Sheath of spicule (*sh.*, fig. 139) very long, covered with little spines and with a bulbous enlargement at end when evaginated.

*Female* 50 to 70 mm. long; anterior portion of body equal to about two-thirds the total length. Eggs (fig. 140) dark brown in color, lemon-shaped, 70 to 80$\mu$ long, including the opercula, or 55 to 65$\mu$ excluding them, and3 0 to 35$\mu$ broad.

HOSTS.—*Sheep (*Ovis aries*); *cattle (*Bos taurus*); *goat (*Capra hircus*); *moose (*Alce americanus*); Dorcas gazelle (*Gazella dorcas*); chamois (*Rupicapra rupicapra*); roe deer (*Capreolus capreolus*); giraffe (*Giraffa camelopardalis*); Bactrian camel (*Camelus bactrianus*); Arabian camel (*Camelus dromedarius*); *mule deer (*Odocoileus hemionus*); marsh deer (*Blastocerus paludosus*); red brocket (*Mazama rufa*); European elk (*Alce alces*); *spotted deer (*Cervus axis*); *fallow deer (*Dama dama*); stag (*Cervus elaphus*); llama (*Auchenia glama*); argali (*Ovis ammon*); *Mexican mountain sheep (*Ovis mexicana*); *Newfoundland caribou (*Rangifer terrænovæ*); prong-horned antelope (*Antilocapra americana*).

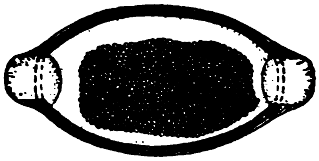

FIG. 140.—*Trichuris ovis.* Egg. × 600. (Original.)

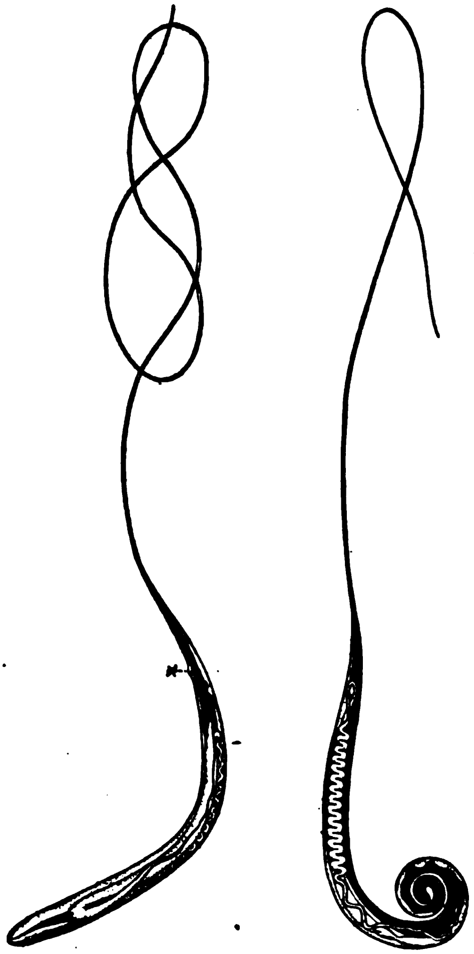

FIG. 138.—*Trichuris ovis.* Male at right, female at left. *Vulva. × 5. (After Curtice, 1890c, pl. 8, figs. 2, 3.)

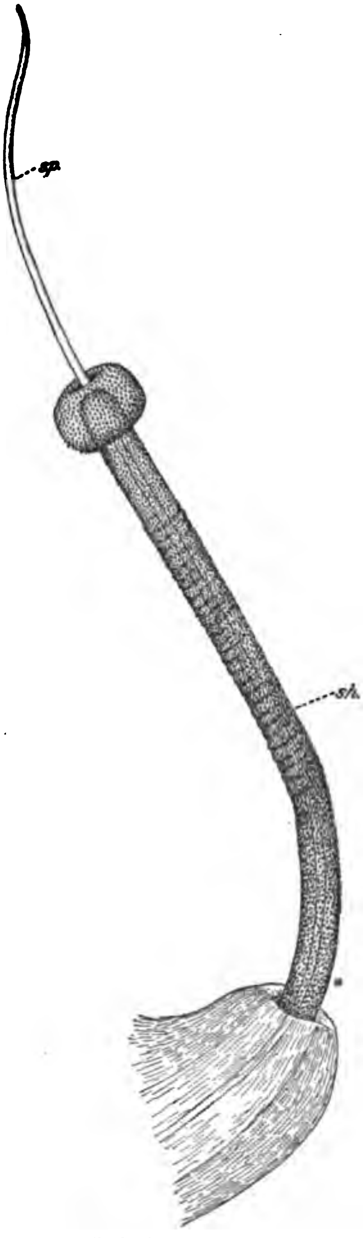

FIG. 139.—*Trichuris ovis.* Posterior end of body of male, with exserted spicule (*sp.*) and spicule sheath (*sh.*) Enlarged. (After Curtice, 1890c, pl. 28, fig. 4.)

LOCATION.—Large intestine, rarely in other parts of the alimentary tract.

LOCALITIES COLLECTED.—United States, Europe, Asia, Africa, South America, New Zealand, Australia.

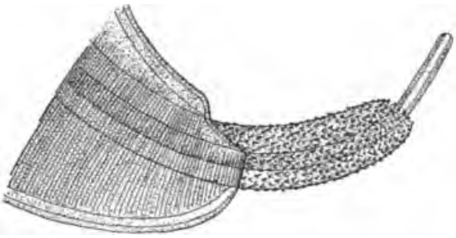

FIG. 141.—*Trichuris discolor*. Posterior end of body of male with exserted spicule and spicule sheath. Lateral view. Enlarged. (After Linstow, 1906, pl. 1, fig. 13).

This species is a common parasite, and has been frequently reported in various ruminants from all parts of the world. It is commonly met with in cattle, sheep, and goats in the United States. It apparently causes little if any trouble.

Leuckart (1868a, pp. 497–502) demonstrated experimentally that this species develops directly from the egg stage without intermediate host and without free-living stages. Eggs of the parasite kept in a moist medium in his laboratory from February to August contained fully formed embryos at the end of this time, which continued their development when fed to a lamb. How long the eggs may retain their vitality is uncertain, probably, however, several years.

**Trichuris discolor** (Linstow, 1906) Ransom, 1911.

(Figs. 141-142.)

1906: *Trichocephalus discolor* Linstow, 1906, Spolia Zeylanica, Colombo, pt. 11, v. 3; Jan., pp. 164, 173, pl. 1, figs. 13–14 (from *Bibos indicus* [=*Bos indicus*], Ceylon).

1911: *Trichuris discolor* (Linstow) Ransom, 1911, pp. 15, 111, 114, 121, figs. 141–142 (the present paper).

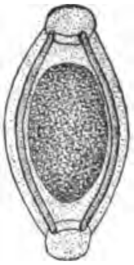

FIG. 142.—*Trichuris discolor*. Egg. Enlarged. (After Linstow, 1906, pl. 1, fig. 14.)

SPECIFIC DIAGNOSIS.—*Trichuris* (p. 111): Cuticle annulate at intervals of 9.1$\mu$; contour of the anterior portion of body serrate.

*Male* white, 45 mm. long by 0.14 mm. thick in front, 0.55 mm. behind; sheath of spicule spinose; spicule long and narrow, of even width except at the rounded apex, 1.76 mm. long by 11$\mu$ thick; hence not to be confounded with *T. ovis*.

*Female* 50 mm. long by 0.13 mm. thick in front, 0.67 mm. behind; anterior portion of body white, posterior portion yellow; eggs (fig. 142) 65 by 35$\mu$ with large spherical opercula at the poles.

HOST.—Zebu (*Bos indicus*).

LOCATION.—Stomach (?).

LOCALITY COLLECTED.—Ceylon.

The above description is taken from Linstow (1906, Spolia Zeylanica, Colombo, pt. 11, v. 3, Jan., p. 164).

### **Trichuris alcocki** (Linstow, 1906) Ransom, 1911.

(Fig. 143.)

1906: *Trichocephalus alcocki* Linstow, 1906, Zool. Jahrb., Abt. f. Syst., v. 24 (1), pp. 7–8, pl. 1, fig. 9 (from intestine of *Cervus eldi*, India).

1911: *Trichuris alcocki* (Linstow) Ransom, 1911, pp. 15, 112, 115, 123, fig. 143 (the present paper).

Specific diagnosis.—*Trichuris* (p. 111): Annular striations of anterior portion of body at intervals of 6.5μ, interrupted by the bacillary band, whose breadth is equal to about seven-tenths of the diameter of the body. The annular striations give the anterior portion of the body a serrate contour.

*Male* 65 mm. long by 0.2 mm. in thickness anteriorly, 0.7 mm. posteriorly. Length of anterior portion of body three times the length of the posterior portion. Tail curved dorsalward in a semicircle. Spicule 3 mm. long, 8μ thick, attenuated at the end. Sheath of spicule, when evaginated a distance of 260μ, measures 26μ broad, is without posterior enlargement, and is armed with regularly arranged powerful spines. The spines are conical in shape and arranged in 20 longitudinal rows.

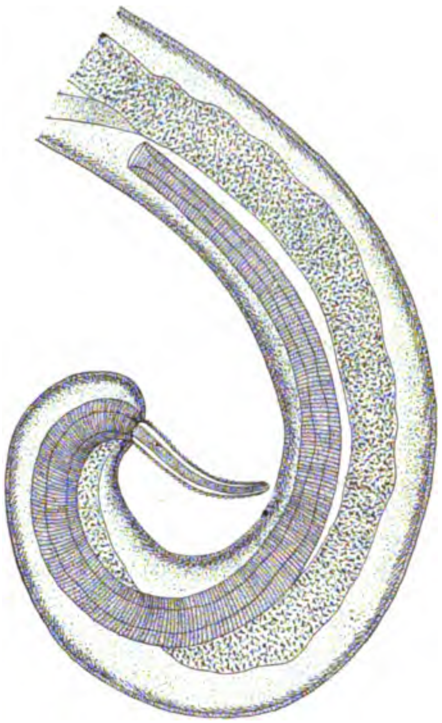

Fig. 143.—*Trichuris alcocki*. Posterior end of body of male. Lateral view. Enlarged. (After Linstow, 1906, pl. 1, fig. 9.)

*Female* 62 mm. long by 0.2 mm. in thickness anteriorly, 0.86 mm. posteriorly. Anterior portion of body about 4½ times as long as the posterior portion. Anus nearly terminal, slightly ventral. Eggs with thick shells, 52μ long by 31μ wide.

Host.—Thamin (*Cervus eldi*).

Location.—Intestine.

Locality collected.—India.

The foregoing diagnosis is taken from the original description given by Linstow (1906).

### **Trichuris globulosa** (Linstow, 1901) Ransom, 1911.

(Figs. 144–146.)

1901: *Trichocephalus globulosus* Linstow, 1901c, pp. 182–183, pl. 8, figs. 1–3 (from *Camelus dromedarius*).

1911: *Trichuris globulosa* (Linstow) Ransom, 1911, pp. 15, 112, 115–116, 123, figs. 144–146 (the present paper).

Specific diagnosis.—*Trichuris* (p. 111): The lateral bands are visible only in the anterior portion, or esophageal region of the body; their breadth is equal to about one-half the diameter of the body; they are composed of small circular structures closely pressed together; the usually rod-like structures are not recognizable; the cuticle is obliquely annulated at intervals of about 3μ.

*Male* about 40 mm. in length by 120μ in breadth anteriorly and 710μ posteriorly. The esophagus is about two-thirds the length of the body. The spicule is 4.3 mm. long, enlarged at the base; the posterior end tapers gradually to a fine point. The sheath of the spicule is spinose with a globular posteriorly truncated swelling at the end, and may be evaginated a distance of 750μ; the spines are extraordinarily close set and point backwards (i. e., toward the body), measuring about 5μ long, except on the bulbous end where they are farther apart, directed radially, and measure 13μ in length. The seminal vesicle is about 8 mm. long.

*Female* attains a length of about 48 mm., with a breadth anteriorly of about 80μ, and a maximum breadth posteriorly of about 870μ. The esophagus is about three-fourths the length of the body. Vulva close behind the posterior end of the esophagus. Egg shell thin with a circular opening at each pole closed by a globular operculum. Length of egg including the opercula 68μ, without these, 60μ; breadth, 36μ.

HOST.—Arabian camel (*Camelus dromedarius*).

LOCATION.—?

LOCALITY COLLECTED.—?Germany.

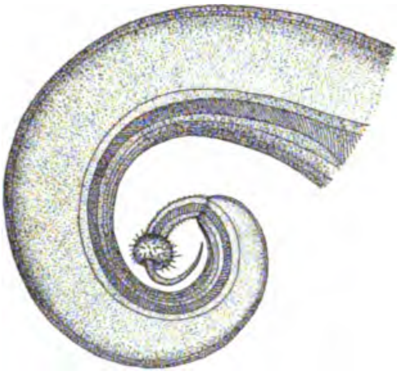

FIG. 144.—*Trichuris globulosa.* Posterior end of body of male. Lateral view. Enlarged. (After Linstow, 1901c, pl. 8, fig. 1.)

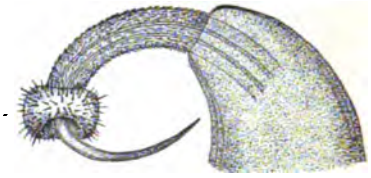

FIG. 145.—*Trichuris globulosa.* Posterior end of body of male. Lateral view. Enlarged. (After Linstow, 1901c, pl. 8, fig. 2.)

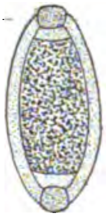

FIG. 146.—*Trichuris globulosa.* Egg. Enlarged. (After Linstow, 1901c, pl. 8, fig. 3.)

This species was described from specimens in the Senckenberg Museum at Frankfort-on-the-Main. The above diagnosis is based on Linstow's (1901c) original description.

**Trichuris cameli** (Rudolphi, 1819) Ransom, 1911.

1819: *Trichocephalus cameli* Rudolphi, 1819a, pp. 18, 228 (from large intestine, *Camelus bactrianus* and *Camelus dromedarius*).

1849: *Trichocephalus echinophyllus* Nitzsch in Creplin, 1849a, p. 58 (from *Camelus dromedarius*. According to Railliet 1893a, p. 483, this species is probably identical with *Trichocephalus cameli* Rudolphi).

1911: *Trichuris cameli* (Rudolphi) Ransom, 1911, pp. 15, 111, 116–117, 123 (the present paper).

SPECIFIC DIAGNOSIS.—*Trichuris* (p. 111): Anterior portion of body equal to about three-fourths the total length. Spicule of male long, filiform, flat, terminating in a point. Sheath of spicule when evaginated covered with numerous spines and with a button-like enlargement at its extremity.

HOSTS.—Arabian camel (*Camelus dromedarius*); Bactrian camel (*Camelus bactrianus*).

LOCATION.—Large intestine.

LOCALITY COLLECTED.—Europe.

The Bureau of Animal Industry collection of parasites contains specimens of *Trichuris*, possibly belonging to this species, collected from a dromedary which died at the National Zoological Park, Washington, D. C.

### **Trichuris giraffæ** (Diesing, 1851) Ransom, 1911.

1851: *Trichocephalus giraffæ* Diesing, 1851a, p. 294 (from *Camelopardalis giraffa* [=*Giraffa camelo-pardalis*]).
1911: *Trichuris giraffæ* (Diesing) Ransom, 1911, pp. 15, 111, 117, 123 (the present paper.)

Specific diagnosis.—*Trichuris* (p. 111): Total length 75 to 100 mm. Anterior portion of body four-fifths the total length.

Host.—Giraffe (*Giraffa camelopardalis*).

Location.—Small intestine.

Locality collected.—Egypt.

All that is known concerning this form is that Clot-Bey (1839, Bull. scient. acad. impériale d. sc. St. Petersbourg (126), v. 6 (6), 19 août, pp. 94–95) found some whip worms of the size given, in the small intestine of a giraffe which died after having been kept at Cairo about one year.

### **Genus CAPILLARIA Zeder, 1800.**

1800: *Capillaria* Zeder, 1800a, p. 5.
1819: *Trichosoma* Rudolphi, 1819a, pp. 13–16, 219–223 (*Capillaria* renamed).
1839: *Trichosomum* Creplin, 1839a, p. 278 (*Trichosoma* renamed).
1845: *Calodium* Dujardin, 1845a, pp. 4, 25–29 (?type species, *C. annulosum*).

Generic diagnosis.—Trichurinæ (p. 111): Body very slender, capillary. Bacillary bands present, dorsal, ventral, or lateral in position. Esophagus long and slender, gradually increasing in size posteriorly. Tail of male may be provided with membranous wings, and a membranous bursa-like structure, which are usually inconspicuous. Spicule long and slender surrounded by a sheath whose outer surface when the sheath is evaginated may be smooth or armed with spines. Vulva located near the base of the esophagus. Eggs ellipsoidal. Egg shell with an opening at each pole closed by a plug-like operculum.

Type species.—*Capillaria tumida* Zeder, 1803=*Trichosoma brevicolle* Rudolphi, 1819.

Three species of *Capillaria* occur in ruminants.

KEY TO SPECIES OF CAPILLARIA.

Male 8 to 9 mm. long, female about 12 mm. long; spicule about 0.9 mm. long. *Capillaria brevipes*, p. 117
Male 11 to 13 mm. long, female about 20 mm. long; spicule about 1.2 mm. long. *Capillaria longipes*, p. 119
Male about 12 mm. long, female about 20 mm. long........... *Capillaria bovis*, p. 120

### **Capillaria brevipes** Ransom, 1911.

(Figs. 147–149.)

1911: *Capillaria brevipes* Ransom, 1911, pp. 15, 117–119, 122, figs. 147–149 (the present paper).

Specific diagnosis.—*Capillaria* (p. 117): Body very slender, gradually increasing in size from the head backward, reaching its maximum thickness in the posterior region of the body some distance in front of the tail, toward which the thickness of the body again diminishes. Head less than 10μ in diameter.

*Male* 8 to 9 mm. long by 50μ in maximum thickness. Esophagus about 4 mm. in length. Spicule (*sp.*, fig. 148) about 0.9 mm. long. Sheath of spicule (*sh.*, fig. 148) considerably longer than the spicule, and when extruded about 10μ in diameter, without spines. Tail curved. Along each side of the posterior end of the body, beginning 200 to 300$\mu$ from the tip of the tail, there is a narrow membranous wing (*l. m.*, fig. 148) terminating opposite the anus, which is subterminal in position. The tail is supplied with a small membranous bursa-like structure (*b. m.*, fig. 148) supported on each side by a small leg-like process originating dorsally from the posterior end of the body. The shorter more slender distal portion of this process is bent forward almost at right angles to its proximal portion, which measures about 15$\mu$ in length.

*Female* about 12 mm. long by 60$\mu$ in maximum thickness. Esophagus about 5 mm. long. Diameter of body at base of esophagus about 50$\mu$. Posterior end of body blunt; anus terminal. Vulva situated just posterior of the base of the esophagus. Eggs (fig. 149) 50$\mu$ long by 25$\mu$ wide, including the opercula, shell 3 to 4$\mu$ thick.

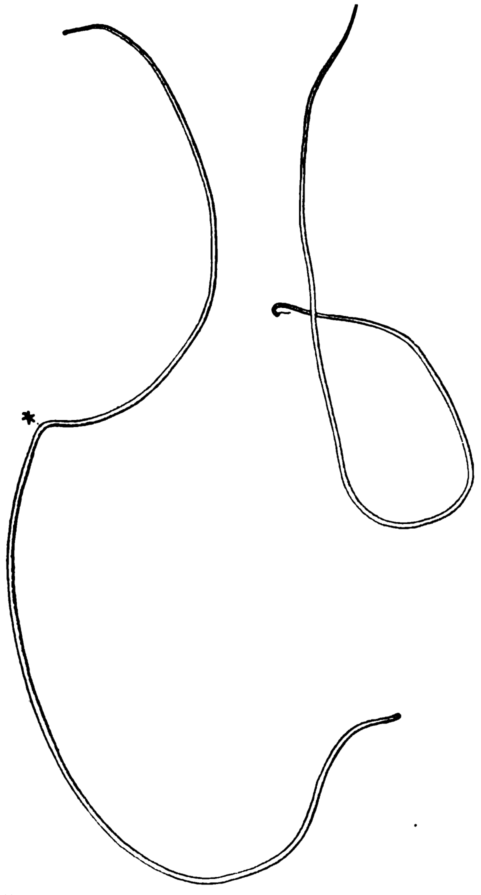

FIG. 147.—*Capillaria brevipes.* Male at right, female at left. *Vulva. × 15. (Original.)

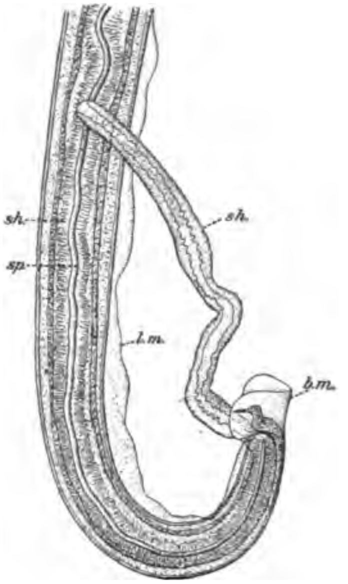

FIG. 148.—*Capillaria brevipes.* Posterior end of body of male. Lateral view. *b. m.*, bursal membrane; *l. m.*, lateral membrane; *sh.*, spicule sheath; *sp.*, spicule. × 300. (Original.)

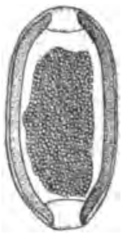

FIG. 149.—*Capillaria brevipes.* Egg. × 600. (Original.)

Host.—* Sheep (*Ovis aries*).

Location.—Small intestine.

Locality collected.—United States.

Type specimens.—Bureau of Animal Industry Helminthological Collection No. 4234, collected January 16, 1906, from the small intestine of a sheep at Bethesda, Md., by Dr. E. C. Stevenson.

This species has been frequently found in sheep at the Bureau of Animal Industry Experiment Station.

### **Capillaria longipes** Ransom, 1911.

(Figs. 150-152.)

1911: *Capillaria longipes* Ransom, 1911, pp. 15, 117, 119-120, 122, figs. 150-152 (the present paper).

SPECIFIC DIAGNOSIS.—*Capillaria* (p. 117): Body very slender, gradually increasing in size from the head backward, reaching its maximum thickness in the posterior region of the body some distance in front of the tail, toward which the thickness of the body again diminishes. Head less than 10$\mu$ in diameter.

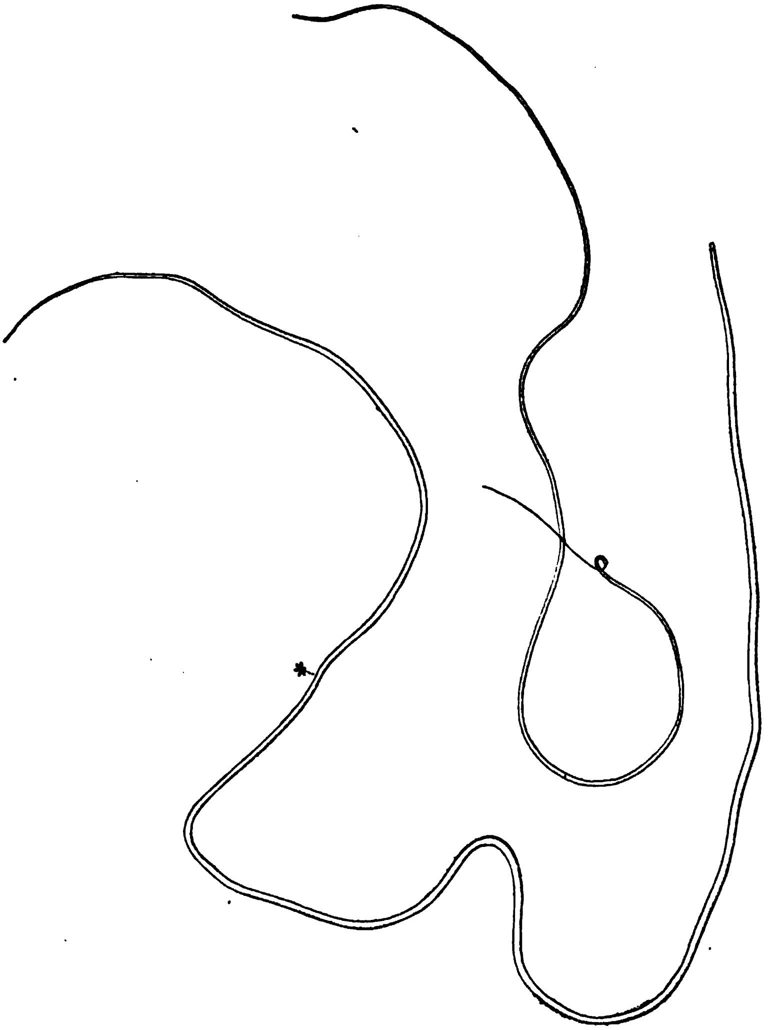

FIG. 150.—*Capillaria longipes*. Male above, female below. *Vulva. × 15. (Original.)

*Male* 11 to 13 mm. long by 50 to 60$\mu$ in maximum thickness. Esophagus 4 to 5 mm. in length. Diameter of body at base of esophagus about 40$\mu$. Spicule (*sp.* fig. 151) about 1.2 mm. long. Sheath of spicule (*sh.*, fig. 151) considerably longer than spicule and about 12$\mu$ in diameter when extruded, without spines. Tail curved.

Along each side of the posterior end of the body beginning about 300μ from the tip of the tail, a rather broad membranous wing (*l. m.*, fig. 151) which extends as far as the anus, which is subterminal in position. Membranous bursa-like structure (*b. m.*, fig. 151) at the tip of the tail supported on each side by a leg-like process whose shorter, more slender distal portion is bent nearly at right angles to its proximal portion, which measures about 30μ in length.

*Female* about 20 mm. long by 80μ in maximum thickness. Esophagus 6 to 7 mm. long. Diameter of body at base of esophagus about 60μ. Posterior end of body blunt; anus terminal. Vulva situated just posterior of the base of the esophagus. Eggs (fig. 152) 45 to 50μ long, including the opercula, by 22 to 25μ wide; shell 1.5 to 2μ thick.

HOST.—* Prong-horned antelope (*Antilocapra americana*); *sheep (*Ovis aries*).

LOCATION.—Small intestine.

LOCALITY COLLECTED.—United States.

TYPE SPECIMENS.—Bureau of Animal Industry Helminthological Collection No. 4222, collected August 13, 1892, from the small intestine of a prong-horned antelope at Washington, D. C., by Dr. A. Hassall.

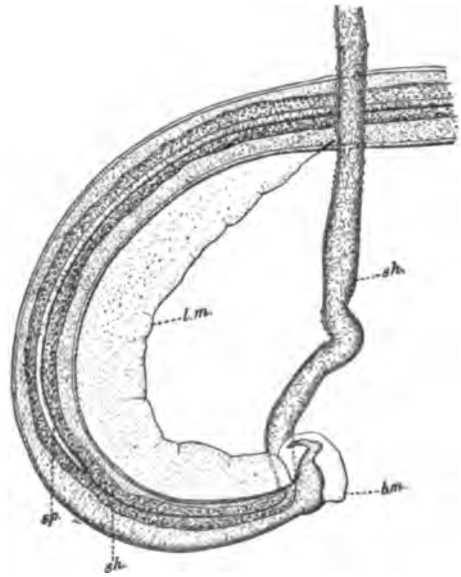

FIG. 151.—*Capillaria longipes*. Posterior end of body of male. Lateral view. *b. m.*, bursal membrane; *l. m.*, lateral membrane; *sh.*, spicule sheath; *sp.*, spicule. × 300. (Original.)

### **Capillaria bovis** (Schnyder, 1906) Ransom, 1911.

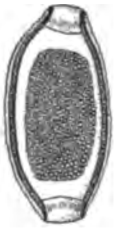

FIG. 152.—*Capillaria longipes*. Egg. × 600. (Original.)

1906: *Trichosoma bovis* Schnyder, 1906a, p. 28 (from *Bos taurus*, Europe).

1911: *Capillaria bovis* (Schnyder) Ransom, 1911, pp. 15, 117, 120, 121 (the present paper).

SPECIFIC DIAGNOSIS.—*Capillaria* (p. 117): *Male* about 12 mm. long by 75μ thick in the posterior region of the body.

*Female* about 20 mm. long by 95μ thick in the posterior region of the body. Eggs 47μ long by 27μ wide.

HOST.—Cattle (*Bos taurus*).

LOCATION.—Small intestine.

LOCALITY COLLECTED.—Switzerland.

Schnyder (1906a, pp. 28, 36) gives only a very brief description of this form, from which the above diagnosis is taken.

### Subfamily TRICHINELLINÆ Ransom, 1911.

SUBFAMILY DIAGNOSIS.—Trichinellidæ (p. 110): Male without spicule. Female ovoviviparous. Adults in intestine of host produce larvæ which penetrate into the muscles, become encysted, and develop to maturity when the flesh of this host is swallowed by another animal.

TYPE GENUS.—*Trichinella* Railliet, 1895.

### KEY TO GENERA OF TRICHINELLINÆ.

One genus.......................................................*Trichinella*, p. 121

## Genus TRICHINELLA Railliet, 1895.

### Trichinella spiralis (Owen, 1835) Railliet, 1895.

*Trichinella spiralis* is mentioned only as of passing interest in the present connection. The adults of this species may occur in the intestine of ruminants as the result of accidentally swallowing flesh infested with the encysted larvæ, but there is little likelihood of their ever being discovered unless they are specially looked for at the proper time after the ingestion of trichinous flesh, as, for example, in experimental infections.

## COMPENDIUM OF SPECIES ARRANGED ACCORDING TO HOSTS.[a]

## Order GLIRES.

### FAMILY LEPORIDÆ.

**Lepus cuniculus. Rabbit.**

* *Strongyloides papillosus*,[b] p. 105.

## Order UNGULATA.

### Suborder ARTIODACTYLA.

### FAMILY BOVIDÆ.

**Addax nasomaculatus. Addax.**

*Hæmonchus contortus*, p. 50.

**Bison bison. American Bison.**

* *Hæmonchus contortus*, p. 50.

**Bos grunniens. Yak.**

*Monodontus longecirratus*, p. 34.

**Bos indicus. Zebu.**

*Ascaris vitulorum*, p. 25.
*Agriostomum vryburgi*, p. 27.
*Monodontus phlebotomus*, p. 31.
*Nematodirus digitatus*, p. 85.
*Gongylonema scutatum*, p. 100.
*Gongylonema verrucosum*, p. 102.
*Trichuris discolor*, p. 114.

**Bos taurus. Domestic ox.**

*Ascaris vitulorum*, p. 25.
* *Monodontus phlebotomus*, p. 31.
* *Chabertia ovina*, p. 35.
? *Œsophagostomum columbianum*, p. 41.
* *Œsophagostomum radiatum*, p. 44.
* *Hæmonchus contortus*, p. 50.
* *Ostertagia ostertagi*, p. 56.
* *Cooperia punctata*, p. 74.
* *Cooperia oncophora*, p. 77.
* *Cooperia pectinata*, p. 81.
* *Nematodirus filicollis*, p. 82.
* *Trichostrongylus extenuatus*, p. 94.
* *Gongylonema scutatum*, p. 100.
* *Trichuris ovis*, p. 112.
*Capillaria bovis*, p. 120.

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[a] The author is indebted to Mr. E. A. Preble, Bureau of Biological Survey, United States Department of Agriculture, and to Mr. N. Hollister, United States National Museum, for their assistance in selecting the names of hosts used in this paper.

[b] The asterisk (*) signifies that specimens of the species indicated have been collected in the United States from the host under which it is listed and that these specimens have been examined by the author.

### Capra hircus. Domestic goat.

* *Monodontus trigonocephalus*, p. 28.
* *Chabertia ovina*, p. 35.
* *Œsophagostomum columbianum*, p. 41.
* *Œsophagostomum venulosum*, p. 46.
* *Hæmonchus contortus*, p. 50.
* *Ostertagia circumcincta*, p. 59.
* *Ostertagia trifurcata*, p. 62.
* *Cooperia curticei*, p. 71.
* *Nematodirus filicollis*, p. 82.
* *Trichostrongylus instabilis*, p. 88.
* *Trichostrongylus vitrinus*, p. 92.
* *Trichostrongylus extenuatus*, p. 94.
* *Trichostrongylus capricola*, p. 96.

*Gongylonema scutatum*, p. 100.

* *Strongyloides papillosus*, p. 105.
* *Trichuris ovis*, p. 112.

### Capra ibex. Alpine Ibex.

*Eucyathostomum spinulosum*, p. 40.

### Gazella dorcas. Dorcas Gazelle.

*Chabertia ovina*, p. 35.
*Trichostrongylus instabilis*, p. 88.
*Trichostrongylus probolurus*, p. 90.
*Trichuris ovis*, p. 112.

### Oryx leucoryx. White oryx.

*Chabertia ovina*, p. 35.

### Ovis ammon. Argali.

*Chabertia ovina*, p. 35.
*Œsophagostomum venulosum*, p. 46.
*Hæmonchus contortus*, p. 50.
*Trichuris ovis*, p. 112.

### Ovis aries. Domestic sheep.

* *Ascaris ovis*, p. 25.
* *Monodontus trigonocephalus*, p. 28.
* *Chabertia ovina*, p. 35.
* *Œsophagostomum columbianum*, p. 41.
* *Œsophagostomum venulosum*, p. 46.
* *Hæmonchus contortus*, p. 50.

?*Ostertagia ostertagi*, p. 56.

* *Ostertagia circumcincta*, p. 59.
* *Ostertagia trifurcata*, p. 62.
* *Ostertagia marshalli*, p. 62.
* *Ostertagia occidentalis*, p. 67.
* *Cooperia curticei*, p. 71.
* *Cooperia oncophora*, p. 77.
* *Nematodirus filicollis*, p. 82.
* *Trichostrongylus instabilis*, p. 88.

*Trichostrongylus colubriformis*, p. 90.
*Trichostrongylus probolurus*, p. 90.

* *Trichostrongylus vitrinus*, p. 92.
* *Trichostrongylus extenuatus*, p. 94.
* *Trichostrongylus capricola*, p. 96.
* *Gongylonema scutatum*, p. 100.

*Gongylonema verrucosum*, p. 102.

* *Strongyloides papillosus*, p. 105.
* *Trichuris ovis*, p. 112.
* *Capillaria brevipes*, p. 117.
* *Capillaria longipes*, p. 119.

### Ovis canadensis. Mountain sheep.

* *Cooperia oncophora*, p. 77.

### Ovis mexicana. Mexican mountain sheep.

* *Hæmonchus contortus*, p. 50.
* *Trichostrongylus extenuatus*, p. 94.
* *Trichuris ovis*, p. 112.

### Ovis nahura. Bharal.

* *Hæmonchus contortus*, p. 50.
* *Ostertagia ostertagi*, p. 56.
* *Trichostrongylus instabilis*, p. 88.
* *Trichostrongylus extenuatus*, p. 94.

### Rupicapra rupicapra. Chamois.

*Monodontus trigonocephalus*, p. 28.
*Chabertia ovina*, p. 35.
*Œsophagostomum venulosum*, p. 46.
*Hæmonchus contortus*, p. 50.
*Ostertagia brigantiaca*, p. 69.
*Trichuris ovis*, p. 112.

## FAMILY ANTILOCAPRIDÆ.

### Antilocapra americana. Prong-horned antelope.

* *Hæmonchus contortus*, p. 50.
* *Ostertagia circumcincta*, p. 59.
* *Nematodirus filicollis*, p. 82.
* *Trichostrongylus instabilis*, p. 88.
* *Trichostrongylus extenuatus*, p. 94.
* *Trichostrongylus capricola*, p. 96.
* *Strongyloides ovocinctus*, p. 108.

*Trichuris ovis*, p. 112.

* *Capillaria longipes*, p. 119.

## FAMILY GIRAFFIDÆ.

**Giraffa camelopardalis. Giraffe.**

*Trichuris ovis*, p. 112.
*Trichuris giraffæ*, p. 117.

## FAMILY CERVIDÆ.

**Alce alces. European elk.**

*Trichuris ovis*, p. 112.

**Alce americanus. Moose.**

* *Hæmonchus contortus*, p. 50.
* *Trichuris ovis*, p. 112.

**Blastocerus campestris. Pampas deer.**

*Eucyathostomum longesubulatum*, p. 38.

**Blastocerus paludosus. Marsh deer.**

*Spiroptera verrucosa*, p. 104.
*Trichuris ovis*, p. 112.

**Capreolus capreolus. Roe deer.**

*Chabertia ovina*, p. 35.
*Œsophagostomum venulosum*, p. 46.
* *Hæmonchus contortus*, p. 50.
* *Nematodirus filicollis*, p. 82.
* *Trichostrongylus instabilis*, p. 88.
* *Trichostrongylus extenuatus*, p. 94.
*Trichuris ovis*, p. 112.

**Cervus axis. Spotted deer.**

* *Trichuris ovis*, p. 112.

**Cervus elaphus. Stag.**

*Chabertia ovina*, p. 35.
*Strongylus ventricosus*, p. 98.
*Trichuris ovis*, p. 112.

**Cervus eldi. Thamin.**

*Trichuris alcocki*, p. 115.

**Dama dama. Fallow deer.**

*Chabertia ovina*, p. 35.
* *Œsophagostomum venulosum*, p. 46.
*Nematodirus filicollis*, p. 82.
* *Trichuris ovis*, p. 112.

**Mazama nana. Pygmy brocket.**

(? *Hæmonchus*) *bispinosus*, p. 54.
*Spiroptera verrucosa*, p. 104.

**Mazama rufa. Red brocket.**

*Eucyathostomum longesubulatum*, p. 38.
*Trichuris ovis*, p. 112.

**Mazama sp.**

* *Hæmonchus contortus*, p. 50.

**Odocoileus hemionus. Mule deer.**

* *Hæmonchus contortus*, p. 50.
* *Trichostrongylus extenuatus*, p. 94.
* *Trichuris ovis*, p. 112.

**Rangifer terræ-novæ. Newfoundland caribou.**

* *Hæmonchus contortus*, p. 50.
* *Ostertagia circumcincta*, p. 59.
* *Trichostrongylus extenuatus*, p. 94.
* *Trichuris ovis*, p. 112.

## FAMILY CAMELIDÆ.

**Auchenia glama. Llama.**

*Trichuris ovis*, p. 112.

**Camelus bactrianus. Bactrian camel.**

* *Trichostrongylus instabilis*, p. 88.
* *Trichostrongylus probolurus*, p. 90.
*Trichuris ovis*, p. 112.
*Trichuris cameli*, p. 116.

**Camelus dromedarius. Arabian camel.**

*Œsophagostomum venulosum*, p. 46.
*Hæmonchus longistipes*, p. 54.
* *Ostertagia mentulata*, p. 68.
*Nematodirus spathiger*, p. 85.
* *Trichostrongylus instabilis*, p. 88.
*Trichostrongylus probolurus*, p. 90.
*Trichostrongylus vitrinus*, p. 92.
*Trichuris ovis*, p. 112.
*Trichuris globulosa*, p. 115.
*Trichuris cameli*, p. 116.

## Order PRIMATES.

### FAMILY CERCOPITHECIDÆ.

**Papio hamadryas. Arabian baboon.**

*Trichostrongylus instabilis*, p. 88.

### FAMILY HOMINIDÆ.

**Homo sapiens. Man.**

*Hæmonchus contortus*, p. 50.
*Trichostrongylus instabilis*, p. 88.
*Trichostrongylus probolurus*, p. 90.
*Trichostrongylus vitrinus*, p. 92.

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## ADDENDUM.

An important article by Railliet and Henry (1910, Quelques helminthes nouveaux ou peu connus du groupe des Bunostomiens, in Bulletin de la Société de Pathologie exotique, Paris, v. 3 (5), 11 mai, pp. 311–315) has come to hand too late for consideration in the preparation of the present paper.

In conformity with the opinion of these authors I consider that the forms which I have grouped in the subfamily Metastrongylinæ should go into the subfamily Trichostrongylinæ Leiper, 1908 (type genus *Trichostrongylus*). Wherever I have used the name Metastrongylinæ the name Trichostrongylinæ should therefore be substituted. The subfamily Metastrongylinæ is accordingly restricted to include only the genus *Metastrongylus* and certain other genera whose species are parasitic in the respiratory tract and circulatory system.

*Monodontus semicircularis* and *Bunostomum trigonocephalum* are apparently not congeneric. The genus *Bunostomum* may therefore be recognized, with the three species *Bunostomum trigonocephalum*, *B. phlebotomum*, and *B. longecirratum*. These names may be substituted for *Monodontus trigonocephalus*, *M. phlebotomus*, and *M. longecirratus* which have been used in the present paper for the species in question.

In the Strongylinæ should be included the genus *Gaigeria* Railliet and Henry, 1910, closely related to *Bunostomum*. Its type and only known species, *Gaigeria pachyscelis* Railliet and Henry, 1910, has been found in the intestine of sheep in India and Africa and doubtfully in cattle in India.

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(Synonyms are printed in italics; principal page references in bold-faced type.)

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U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF ANIMAL INDUSTRY.—BULLETIN 128.

A. D. MELVIN, CHIEF OF BUREAU.

# THE INFLUENCE OF TYPE AND OF AGE UPON THE UTILIZATION OF FEED BY CATTLE.

INVESTIGATIONS IN COOPERATION WITH THE INSTITUTE OF ANIMAL NUTRITION OF THE PENNSYLVANIA STATE COLLEGE.

BY

HENRY PRENTISS ARMSBY AND J. AUGUST FRIES.

WASHINGTON:
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# LETTER OF TRANSMITTAL.

United States Department of Agriculture,
Bureau of Animal Industry,
*Washington, D. C., January 7, 1911.*

Sir: I have the honor to transmit herewith and to recommend for publication as a bulletin of this bureau a manuscript entitled "The Influence of Type and of Age upon the Utilization of Feed by Cattle," by Dr. Henry Prentiss Armsby and Mr. J. August Fries. The paper describes work done during a period of three years in cooperation between this bureau and the Institute of Animal Nutrition of The Pennsylvania State College.

Two steer calves were selected as the subjects of this investigation, one a purebred typical beef animal of one of the well-known beef breeds, the other a "scrub" of mixed breeding. Exhaustive feeding trials were carried out with these animals, including twenty-four experiments with the respiration calorimeter. Finally the steers were subjected to a slaughter test whereby the quality of the meat and the relative size of the various cuts were accurately determined. The work is therefore important alike to the practical feeder and the agricultural scientist.

Respectfully,

A. D. Melvin,
*Chief of Bureau.*

Hon. James Wilson,
*Secretary of Agriculture.*

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# THE INFLUENCE OF TYPE AND OF AGE UPON THE UTILIZATION OF FEED BY CATTLE.

## INTRODUCTION.

It is a fact of common knowledge that marked differences exist between individual animals as regards the returns which they yield for the feed consumed. In the case of beef cattle especially it is easy to cite from the experimental records of the past numerous instances in which, quite aside from any differences in the quality of the product, the actual gain in weight per pound of feed consumed has varied considerably with different animals under like conditions. It is true that it is almost equally easy to cite experiments which have failed to show any such differences in this respect between typical beef animals and "scrubs" as was confidently anticipated by their projectors, but nevertheless differences in the type and individuality of animals are admittedly of great importance. The tendency has been to ascribe such differences to physiological causes. A common statement is that a good feeder has a greater digestive power than a poor one, although fairly numerous experiments have failed to show any marked differences in the percentage digestibility of the same feeding stuffs by animals of different types. What is really meant by such a statement usually is that the power of assimilation of the one animal is superior to that of the other; that is, it has been assumed that the advantage of the better type of animal lay in its ability to produce more flesh or fat from a unit of feed than could the poorer one.

The existence of such differences in the metabolic processes of individuals of the same species, however, does not seem especially probable. It is difficult to see, for example, how one steer could manufacture more fat than another from a unit weight of a carbohydrate. Moreover, an observed superiority in the amount of gain in live weight made may be conceived to arise from other causes, as, for example, from a difference in the maintenance requirement or in the chemical composition of the increase or from the ability of the one animal to consume a larger amount of feed than the other, while, of course, differences in selling price depend to a very large extent upon the conformation of the animal and the quality of the meat. Nevertheless, we are not warranted in ignoring the possibility that an improved animal or breed may have actually become a more efficient mechanism for converting digested food into tissue, and if such differences do exist, it is obviously of the highest importance, both from the scientific and the practical standpoints, that their existence and their extent be determined. On the one hand, if considerable, they would render futile any attempt to express with scientific accuracy the nutritive values of feeding stuffs, as, indeed, some writers claim to be the case. On the other hand, their practical importance is manifest, not merely in relation to the selection of animals for meat production but especially in their bearing on the problem of the improvement of the breeds of meat-producing animals.

The object of the investigation here reported was to test this question by using two animals of markedly dissimilar type and determining their digestive power for the same feeding stuffs and the proportion of the energy of the latter which they were able to use for maintenance or for productive purposes, respectively.

It has also been commonly taught, and seems to be generally accepted by animal husbandmen as an established fact, that young growing animals not only make relatively larger gains than more mature ones, but likewise more economical gains. While it is true, as Waters[1] has pointed out, that most feeding experiments have exaggerated the differences between young and mature cattle in these respects through failure to take account of the marked influence of the condition of fatness upon the rate and cost of gain, it is, nevertheless, a well-established fact that a given gain in live weight is, other things being equal, obtained more rapidly and with less feed in young than in old animals.

Certainly a large share of this difference, however, is due to the well-known variation in the character of the increase, as has been previously discussed by one of us.[2] The young animal has a remarkable power of storing up protein in the tissues of the body, and the increase in weight of such an animal consists to a great extent of protein tissue with its accompanying large amount of water. As the age of the animal increases, its capacity to store up prôtein diminishes, at first rapidly and then more slowly, while the storage of fat tends to increase. As a result, a unit of gain made by a young animal contains a relatively low percentage of dry matter, which itself has a relatively low energy value. On the other hand, the gain in weight made by a mature animal consists largely of adipose tissue with a low water content and a high energy value, so that a unit of increase in a mature fattening animal may represent the storage of six to eight times as much energy as an equal gain in weight by a very young animal. It is obvious that to produce a unit of increase in weight must require very different amounts of food in the two cases.

---

[1] "Limitations of Baby Beef Production," Thirty-ninth Annual Report Missouri State Board of Agriculture, 1907, pp. 114-166.

[2] Armsby. U. S. Department of Agriculture, Bureau of Animal Industry, Bulletin 108, pp. 11-33.

The energy of the growth process in the young animal is such a striking phenomenon, however, and the feeder is so accustomed to thinking in terms of live weight that the impression has been created that somehow the rapid increase in weight and bulk by the young animal is, in part at least, the result of a greater intrinsic capacity for utilizing its feed. It has been supposed, in other words, that the actual physiological processes involved in the increase of weight are in the growing animal, by virtue of its power of growth, performed more economically than in the mature animal and consequently that a larger percentage of the energy of the food is stored in the form of gain in the younger animal.

It is clear that the truth of this supposition can not be tested by experiments in which only the gain in live weight is ascertained but that it is necessary to know also the make-up of the increase or the amount of energy which it contains. One object of the present investigation was to make comparisons of this sort upon the same animals at different ages, but this object was only partially attained.

## GENERAL PLAN OF INVESTIGATION.

Two steer calves were selected as the subjects of investigation. One of these was a purebred Aberdeen-Angus of typical beef form, while the other was a "scrub" containing considerable Jersey blood and possessing the dairy rather than the beef form. These animals were about 8½ and 11 months old, respectively, at the beginning of the investigation in October, 1904, and were under nearly continuous observation for over 2½ years. During this time, with the exception of certain of the periods in which the balance of matter and energy was determined by means of the respiration calorimeter, they were fed an ordinary growing ration, and while maintained in a thrifty condition were at no time fattened. The feeding stuffs used were of the same kind for both animals in all the periods, and the different grains used were mixed throughout in the same proportions for each steer. The live weights of the animals were taken at least once weekly, as well as on three consecutive days at the end of each month, and they were systematically measured and photographed every three months.

At intervals during this time the digestibility of the total ration and the nitrogen balance were determined for each animal. It was originally intended to make these determinations once in three months, but this proved to be impracticable. In all, four such trials were made in addition to those included in the respiration calorimeter experiments mentioned in the next paragraph, viz, in December, 1904, July, 1905, November, 1905, and June, 1906. On subsequent pages these will be designated as "digestion and metabolism trials."

During each of the three winters covered by the investigation four experiments were made on each animal by means of the respiration calorimeter in order to determine the percentage availability of the energy of the feeds consumed. During the first winter, that of 1904–5, the feeding stuffs used differed from those employed during the ordinary feeding. In the succeeding two winters the grain feeds used were the same, only the amounts differing. The respiration calorimeter experiments, of course, included determinations of the digestibility of the rations and of the nitrogen balances of the animals. They will be designated, for the sake of brevity, as "calorimeter experiments."

For the convenience of the reader, the report of the work is divided into three parts.

Part I consists of a general account of the investigation, summarizing and discussing the principal results, but omitting the details of the respiration calorimeter experiments and of the digestion and metabolism trials.

Part II records the details of the respiration calorimeter experiments and of the digestion and metabolism trials the general results of which are discussed in Part I.

Part III contains the necessary information regarding the technic of the investigation, this being omitted in Parts I and II in order to avoid cumbering the pages and distracting the attention of the reader from the main line of thought.

After the close of the investigation in the spring of 1907 the animals were put on pasture during the summer, were fattened in the fall, and finally used for a demonstration in slaughtering and meat cutting, the weights of the different cuts being recorded.

## GENERAL CONCLUSIONS.

The principal results of the investigation outlined in the foregoing paragraphs may be briefly summarized as follows:

The respiration calorimeter experiments failed to show that either the type or age of the steers exerted any material influence upon the percentage digestibility of the feeding stuffs or upon the proportion of their energy which was metabolized. As regards the percentage of the metabolizable energy which was available either for maintenance or for production, slight differences were observed in favor of the purebred steer and, in case of the grain, of the older as compared with the younger animal, but it is questionable whether they were large enough to be of practical significance.

On the limited grain ration of the periods outside the respiration calorimeter experiments, the scrub steer consumed relatively more hay than did the purebred animal, made an equal gain in live weight per head, and a materially greater one per unit of weight, and consumed somewhat less total air-dry feed per unit of gain.

This apparent discrepancy between the results of the respiration-calorimeter experiments and those of the remainder of the investigation appears to have been due chiefly to a difference in the composition of the increase in live weight in the two animals. The nitrogen balances show a notably greater tendency toward a storage of protein by the scrub than by the purebred steer, while the respiration-calorimeter experiments, on the other hand, show a materially greater gain of fat by the latter than by the former. In other words, the gain in weight by the scrub as compared with that by the purebred steer consisted more largely of protein with its accompanying water and to a smaller extent of fat, and therefore represented a materially smaller storage of feed energy. A similar conclusion was indicated by the results of the block test. From the data obtained for the available energy of the rations it is estimated that a kilogram of gain in live weight by the purebred steer was equivalent on the average to the storage of 40 per cent more energy than in the case of the scrub.

The energy requirement of the scrub steer for maintenance, computed to the same live weight, averaged 18.7 per cent higher than that of the purebred steer. Accordingly, the latter was able to use a relatively larger proportion of the total energy of his ration for the production of gain. A distinct influence of age upon the maintenance requirement was observed between the ages of 14 and 39 months, the requirement decreasing relatively as the animals matured.

In those of the respiration calorimeter experiments in which a heavy grain ration was fed, it was found that the purebred steer had a notably greater feeding capacity than the scrub steer—that is, he could be fed larger rations of grain, which he utilized to the same degree as did the scrub.

While, then, our results fail to show any material differences between the physiological processes of food utilization in the two animals, they also show clearly an economic superiority of the purebred over the scrub steer, due, first, to his relatively smaller maintenance requirement, and, second, to his ability to consume a larger surplus of feed above that requirement. Both these factors tend to make the actual production of human food in the form of meat and fat per unit of total feed consumed by the animal notably greater by the purebred animal. In these experiments this difference was masked by the inferior quality of the increase made by the scrub steer, so that on the basis of live weight alone the latter appears superior to the purebred animal.

Contrary to the conclusions drawn by us from earlier experiments, it was found that the availability of the energy of the grains used was substantially the same above and below the point of maintenance, and that in both cases the energy values as determined by the respiration calorimeter agreed well with those computed from the chemical composition by the use of Kellner's well-known factors. In the case of the hay, on the contrary, the availability below the point of maintenance was considerably greater than the result computed by means of Kellner's factors for the percentage utilization above maintenance.

In the case of the purebred animal especially, and to a less degree in that of the scrub, rations containing less available energy and notably less digestible protein than the amounts called for by the current feeding standards for growing cattle, produced entirely satisfactory gains in live weight.

## ACKNOWLEDGMENTS.

The execution of an investigation covering over 30 months and including, in addition to the usual records of feed, live weight, etc., and numerous measurements and photographs of the animals, 32 digestion and metabolism trials and 24 experiments with the respiration calorimeter, together with the great variety of analytical and clerical work which these all imply, necessarily calls for a considerable staff of assistants. The personnel of this staff underwent considerable changes during the progress of the research, only one of those connected with the work at its inception remaining until the close (Mr. Braman). Moreover, the chemical analyses, as well as the computations and clerical work, incident to the calorimeter experiments and the digestion trials were necessarily performed to a large extent after the completion of the experiments themselves, so that an assistant was often engaged in analyses or computations for experiments in whose immediate execution he had not taken part and otherwise performed work of quite varied nature at different times. In all, aside from a few temporary assistants, 14 persons have had more or less part in the work, viz, in alphabetical order, Messrs. W. W. Braman, J. W. Calvin, T. M. Carpenter, F. W. Christensen, D. C. Cochrane, W. F. Frisbie, N. C. Hamner, R. C. Jones, R. A. Licthenthaeler, W. H. McIntire, N. G. Miller, J. H. Parkins, F. S. Putney, and R. E. Stallings.

For the reasons just indicated, it is impossible even to attempt any statement of the exact part taken by individuals or to make acknowledgments for the specific work done by each person. This is all the more true because the most important factor in whatever success the investigation has attained, and one which by its nature is incapable of such partition, is the loyalty and zeal which all concerned have shown in the execution of the plan of the investigation and in securing the greatest attainable accuracy of details. A scientific investigation of any considerable scope necessarily requires a large amount of routine work any serious defects in which must inevitably render futile the most carefully laid plans. "Team work" is as essential in scientific investigation as on the athletic field, and the ungrudging cooperation of all the assistants in these laborious experiments can not be too emphatically acknowledged. Specific mention should also be made of the valuable advice and cooperation of Dr. William Frear, chemist, and Mr. M. S. McDowell, first assistant chemist of the experiment station, in the execution of the chemical analyses, and of the services of the late William C. Patterson, superintendent of grounds and buildings, in charge of the experiment station farm, to whom we are indebted for the necessary labor and facilities for the experimental feeding and care of the animals.

## PART I. GENERAL ACCOUNT OF THE INVESTIGATION.

### THE ANIMALS.

Since one object of the investigation was to study the influence of the type of animal upon the utilization of the feed, as complete a description as possible of the animals used is essential to enable the reader to judge of the significance of the results. The animals selected were the following:

Steer A, Aberdeen-Angus, Maggie's Baron 2d, 69524. Sire, Bella's Baron, 46381; dam, Maggie of Douglass, 40511. Dropped January 16, 1904. Bred by the Pennsylvania State College.

Steer B, scrub. Sire, probably a scrub; dam, a high-grade Jersey. Dropped about November 7, 1903. Bred by W. I. Thompson, jr., State College, Pa. Purchased July, 1904.

As already stated, the animals were photographed at intervals of approximately three months, a side, front, and rear view being taken in each instance. The negatives are preserved as part of the records of the investigation. All these photographs were taken with the same lens and at the same distance from the subject, so that they are strictly comparable. Plates I, II, and III contain reproductions of photographs taken on October 8, 1904, October 15, 1906, and February 20, 1907, selected as illustrations of the whole series. The pictures show quite clearly that steer A (Aberdeen-Angus) was of the recognized beef form, while steer B (scrub) appears as distinctly to have belonged to the dairy type.

### MEASUREMENTS.

Measurements of the animals were made monthly. The results are recorded in Table I of the appendix, and those relating to length of body, shoulder height, chest girth, and thickness at paunch are represented graphically on figures 1, 2, 3, and 4.

The method employed for measuring the animals was imperfect, and for this or other reasons it is evident that the results were not very accurate, as is indicated by the irregularities of the figures. While differences in the thickness of the animal's coat and variations in the state of fatness may have affected the results, they can hardly account for the considerable fluctuations shown. The following general conclusions, however, appear to be justified.

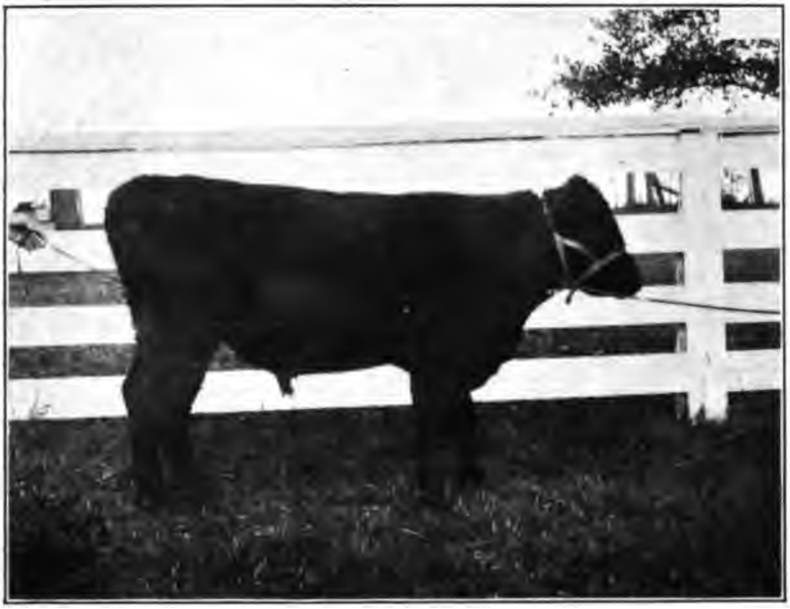

FIG. 1.—THE PUREBRED STEER AT 9 MONTHS OLD, OCTOBER 8, 1904.

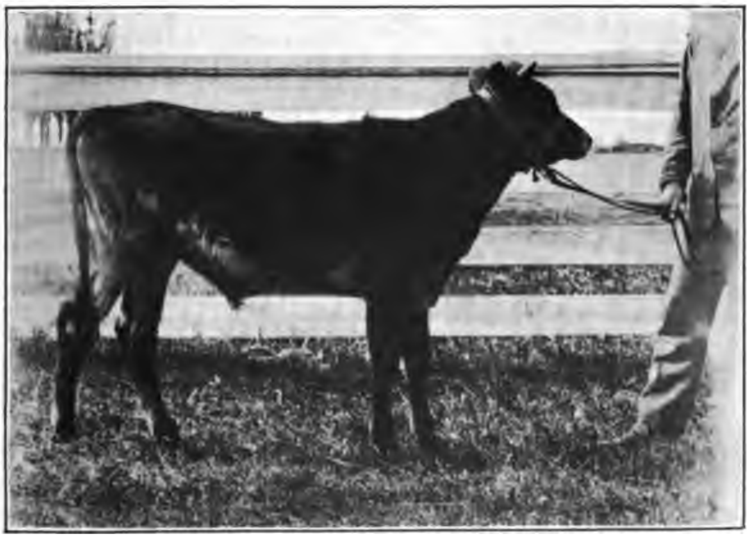

FIG. 2.—THE SCRUB STEER AT 11 MONTHS OLD, OCTOBER 8, 1904.

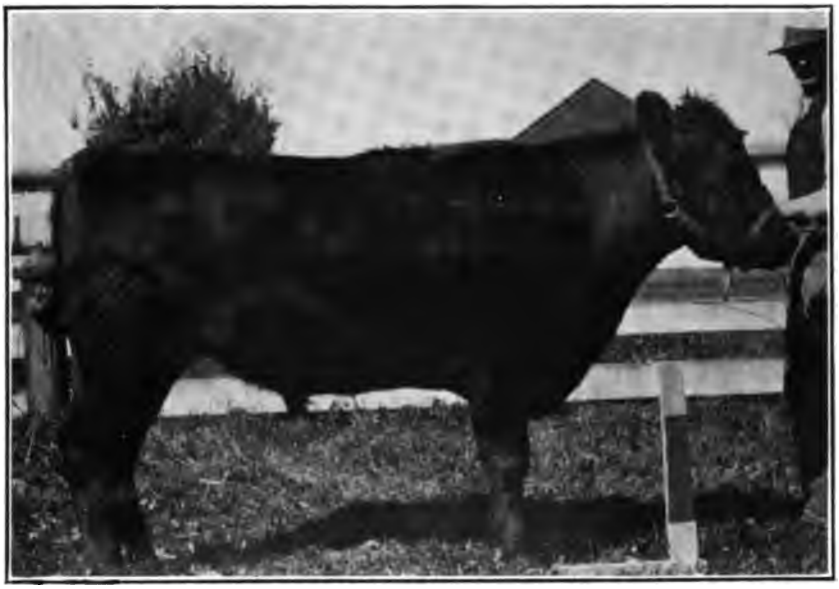

FIG. 1.—THE PUREBRED STEER AT 2 YEARS AND 9 MONTHS OLD, OCTOBER 15, 1906.

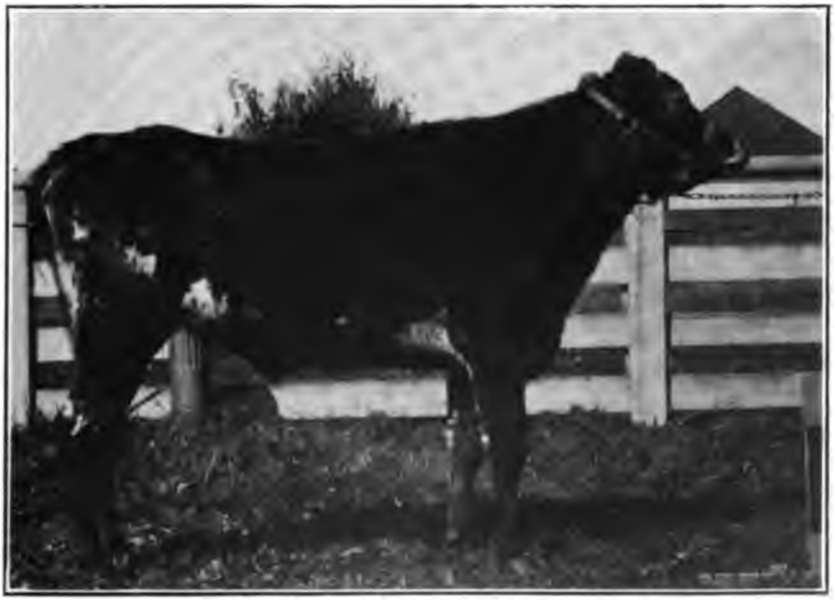

FIG. 2.—THE SCRUB STEER AT 2 YEARS AND 11 MONTHS OLD, OCTOBER 15, 1906.

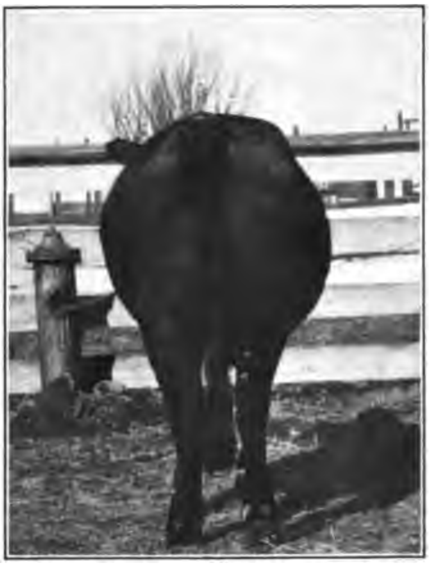

FIG. 1.—THE PUREBRED STEER.

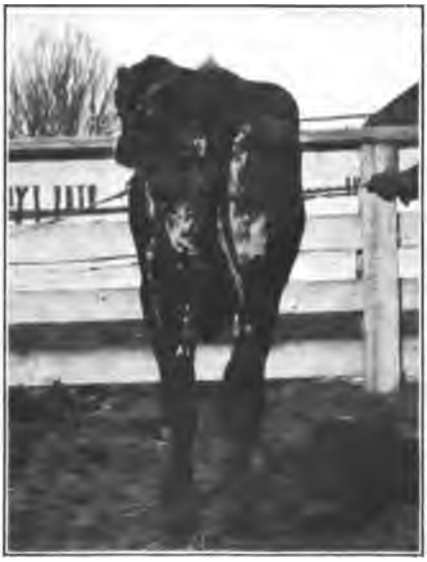

FIG. 2.—THE SCRUB STEER.

REAR VIEW OF THE STEERS ON FEBRUARY 20, 1907.

*Length of body.*—After the irregularities of the first six months, it appears that both animals gained in length at a similar rate for a time. After about November, 1905, however, the growth in length of steer A was much less rapid, while that of steer B continued at about the same rate as heretofore, so that this animal finally overtook steer A.

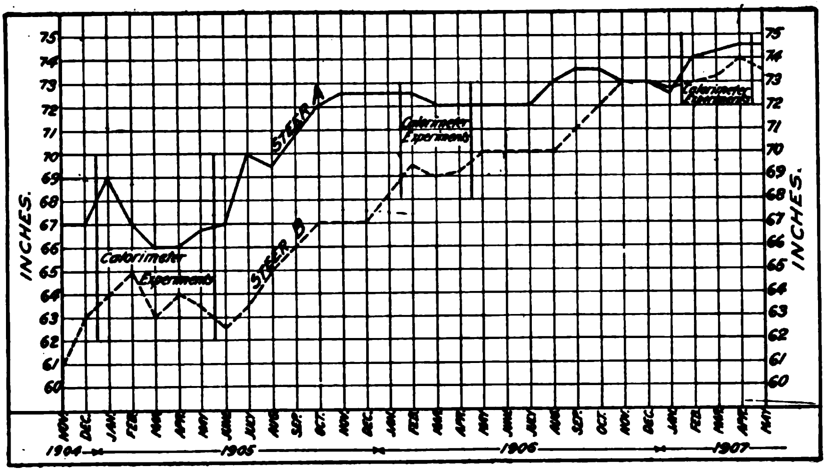

FIG. 1.—Length of body of steers at monthly periods from November, 1904, to May, 1907.

*Shoulder height.*—At the beginning of the experiment both steers were of about the same height. Steer B, however, increased his height much more rapidly than did steer A. In both the rate of increase appears to have diminished as the animals grew older, but this effect is rather more marked with steer B than with steer A.

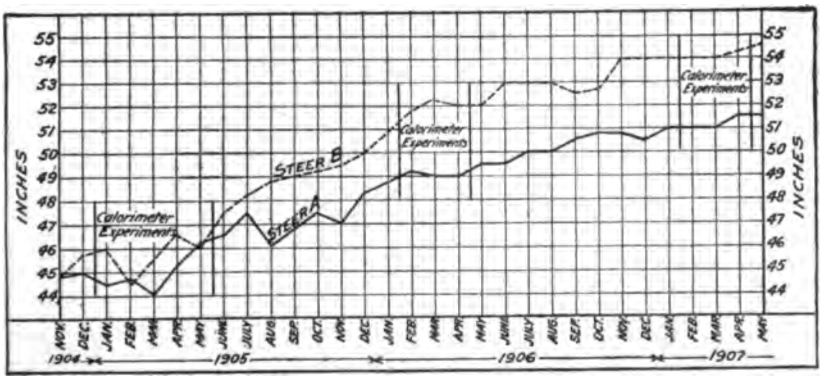

FIG. 2.—Height at shoulder of steers at monthly periods from November, 1904, to May, 1907.

*Chest girth.*—Steer B was inferior in chest girth to steer A, but his growth in this respect was fully as rapid as that of the latter. After about July, 1906, however, the rate for steer B falls off much more rapidly than that for steer A.

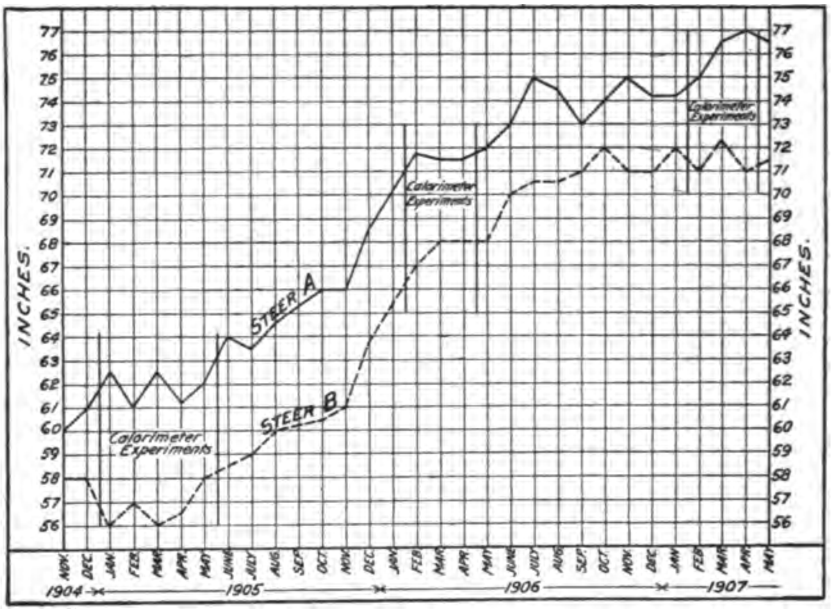

FIG. 3.—Chest girth of steers at monthly periods from November, 1904, to May, 1907.

It is plain from these comparisons that the increase in weight of steer A was due much more largely than that of steer B to an increase

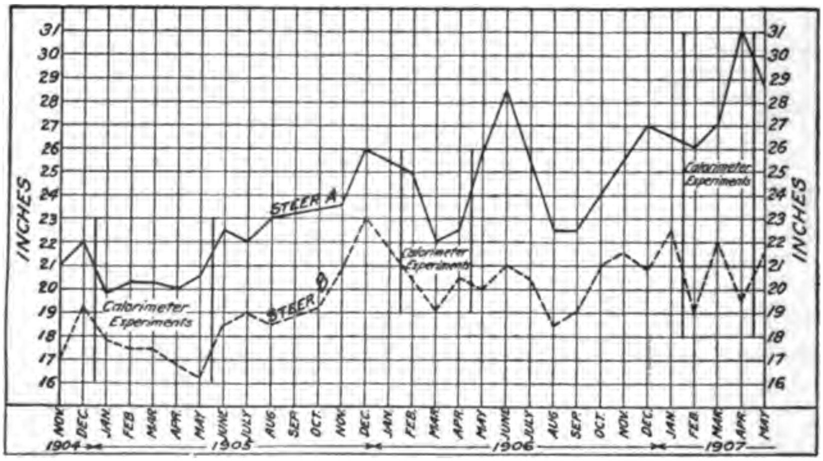

FIG. 4.—Thickness at paunch of steers at monthly periods from November, 1904, to May, 1907.

in the size of body, particularly in cross section. Steer B, on the other hand, gained more markedly in length and height.

## LIVE WEIGHTS.

The live weights taken are recorded in Table II of the appendix and are represented graphically in figure 5, which shows the average live weights at the beginning of each month as recorded in Table IIa of the appendix. A comparison of these results shows that steer A steadily increased in live weight with but partial interruption by the calorimeter experiments. Steer B, on the other hand, shows a perceptibly slower rate of increase after the first year, while his growth, measured by live weight, was much more affected by the limited rations of the calorimeter experiments. A comparison of these results with those of the measurements and with the photographs taken shows that steer A made his gains of weight largely by increase in depth and width of body, while the growth of steer B was much more "rangy."

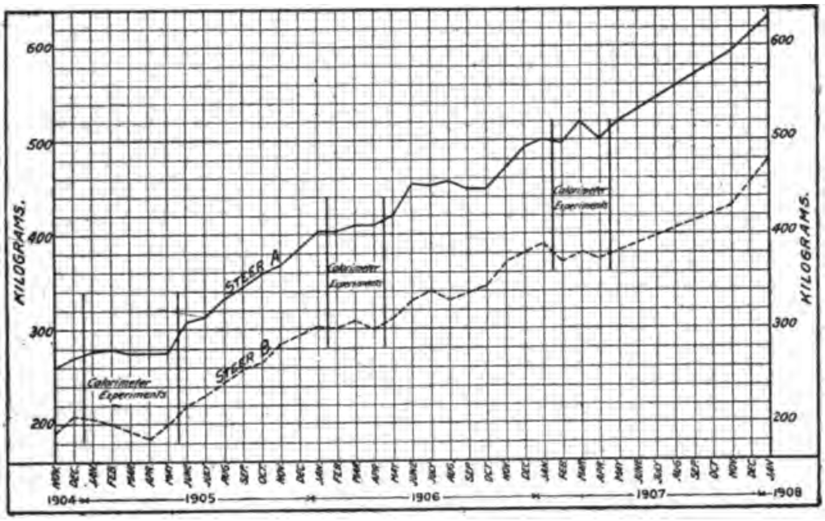

FIG. 5.—Live weights of steers, monthly, from November, 1904, to January, 1908.

It does not appear from the foregoing that the introduction of a period of light or insufficient feeding each year permanently affected the growth of the animals. It is true that steer B made little or no gain on the light rations of the calorimeter experiments, although steer A still showed some increase. The calorimeter experiments, amounting in all to about nine months, were largely lost time so far as gain in weight was concerned, but with the return to liberal rations, the gain apparently proceeded without any serious check, while the increase in size of the animal appears to have been much less affected than the increase in weight.

On December 4, 1906, the actual ages of the two animals were: Steer A, 34.5 months; steer B, 37 months. The periods during which actual productive feeding was carried on, however, amounted (omitting the period July 4–28, 1906, in which no gain was made) to 17.7 months for steer A and 16.6 months for steer B,[1] so that what we might call their virtual ages and the corresponding live weights at the close of the feeding, were:

Steer A, 26.2 months old; live weight, 1,089 pounds.
Steer B, 27.5 months old; live weight, 834 pounds.

The weight of steer A was at least fairly good for an unfattened animal at that age.

After December 4, 1906, there followed another experimental period of low feeding, during which, however, steer A gained materially (about 73 pounds). Following this the animals were on pasture for about six months, making their weights and virtual ages, October 28, 1908:

Steer A, 32 months old; live weight, 1,307 pounds.
Steer B, 33 months old; live weight, 943 pounds.

Two months later, January 4, 1908, they weighed after fattening: Steer A, 1,392 pounds; steer B, 1,063 pounds.

At most, the periods of maintenance and submaintenance seem only to have rendered the rate of gain in weight slightly less rapid, but not to have prevented the final attainment of a fairly satisfactory weight nor the production of a good quality of beef. It is also to be noted that up to the close of the records the animals were still increasing both in weight and size, showing that they had not yet completed their growth and indicating that the effect of scanty feeding is to delay rather than to diminish growth. This conclusion is entirely in harmony with the very interesting results upon the growth of animals under adverse conditions reported by Waters.[2]

### BLOCK TEST.

As previously noted, both the animals were used for a demonstration in slaughtering and meat cutting, the work being conducted by Mr. W. H. Tomhave. The animals were killed on January 4, 1908. Steer B was not as well fattened as steer A, being rated as "common," while steer A was graded as "prime." Table 1 shows the total dressed weight and the weights of the several wholesale cuts expressed as percentages of the live weight and of the dressed weight, respectively.

---

[1] Compare Table 52, p. 78.

[2] Society for the Promotion of Agricultural Science. Proceedings, 1908, pp. 71-96.

TABLE 1.—*Weights and percentages of wholesale cuts.*

| Cuts. | Steer A (Aberdeen-Angus). | | | Steer B (scrub). | | |
|---|---|---|---|---|---|---|
| | Weight of cuts. | Live weight. | Dressed weight. | Weight of cuts. | Live weight. | Dressed weight. |
| | *Pounds.* | *Per cent.* | *Per cent.* | *Pounds.* | *Per cent.* | *Per cent.* |
| Round | 182.50 | 13.08 | 21.79 | 130.50 | 12.25 | 22.50 |
| Loin | 146.25 | 10.49 | 17.46 | 95.25 | 8.94 | 16.42 |
| Suet | 33.75 | 2.43 | 4.03 | 10.25 | .96 | 1.77 |
| Flank | 43.50 | 3.12 | 5.20 | 20.00 | 1.88 | 3.45 |
| Ribs | 82.00 | 5.88 | 9.79 | 59.00 | 5.53 | 10.12 |
| Chuck | 249.50 | 17.90 | 29.79 | 195.00 | 18.31 | 33.62 |
| Plate | 99.75 | 7.15 | 11.94 | 70.25 | 6.59 | 12.12 |
| Total | 837.25 | 60.05 | 100.00 | 580.25 | 54.48 | 100.00 |

These results show the considerably higher percentage of dressed weight in the case of steer A which is characteristic of the beef animal, and likewise the predominance of the loin cut over the less valuable cuts in the forequarter in the beef animal as compared with the scrub.

The following comparison of the marketable meat of the retail cuts likewise shows that the proportion of the more valuable cuts was notably greater in steer A than in steer B:

TABLE 2.—*Marketable meat in retail cuts.*

| Cuts. | Steer A (Aberdeen-Angus). | | | Steer B (scrub). | | |
|---|---|---|---|---|---|---|
| | Weight. | Dressed weight. | Marketable meat. | Weight. | Dressed weight. | Marketable meat. |
| | *Pounds.* | *Per cent.* | *Per cent.* | *Pounds.* | *Per cent.* | *Per cent.* |
| Round steak, rump, sirloin steak, porterhouse steak, and prime ribs | 337.00 | 40.25 | 44.24 | 222.25 | 38.32 | 42.46 |
| All other cuts | 424.75 | 50.74 | 35.76 | 301.25 | 52.14 | 57.54 |

The evidence of the block as well as of scales and tape line confirms that of the eye in characterizing steer A as a beef animal as contrasted with steer B.

## THE RESPIRATION CALORIMETER EXPERIMENTS.

In studying the records of the animals just described while under experiment it will be convenient to consider first the results obtained in the respiration calorimeter experiments, taking up subsequently the records of the intermediate feeding periods and of the digestion and metabolism trials included in them.

### PLAN OF RESPIRATION CALORIMETER EXPERIMENTS.

As stated in the introduction, the prime object of the investigation was to compare the total metabolism of the two animals at different ages when fed upon rations made as nearly comparable as possible for the purpose, especially, of determining whether the age or type of animal exerted any perceptible influence upon the percentage availability or percentage utilization of the energy of the ration, using these terms in the senses defined in our previous publications.

The income and outgo of matter and of energy was accordingly determined for each animal by means of the respiration calorimeter during January to April, 1905, 1906, and 1907 on four different rations, making 24 experiments in all. The general plan for each year was the same, being substantially that followed in the experiments upon the energy values of red-clover hay and corn meal reported in a previous bulletin.[1] In two periods upon hay alone different amounts were fed, one ration being intended to be slightly and the other considerably below the maintenance requirement. A comparison of these two periods served to determine the availability of the energy of the hay. In a third period grain was added to the smaller of the two hay rations in amount estimated to be nearly sufficient to reach the maintenance point, thus affording data for computing the availability of the energy of the grain. Finally, in a fourth period, as heavy a grain ration as was thought practicable was fed in conjunction with the same amount of hay, so that a comparison of the third and fourth periods would show the percentage utilization of the energy of the grain. As will appear in the following pages, the actual chronological order of the experiments differed from that just stated.

With a view to securing, in addition to the main results sought, data as to the energy values of individual feeding stuffs, the attempt was made in the experiments of 1905 to substitute wheat bran for the mixture of grains used up to that time, while timothy hay was employed in place of mixed hay on account of its being a more definite material. The substitution of bran for the mixed grain proved unfortunate in some respects. The animals did not appear to relish it and the amounts eaten were relatively small, even in the periods of heaviest feeding. It is possible that these facts may in some degree account for the irregularity of the results in that year.

In the respiration-calorimeter experiments of the two succeeding winters, therefore, the attempt to determine the energy values of single grains was abandoned and the same mixture of grains employed as was used in the intermediate periods up to April 12, 1906 (compare p. 60), viz:

| | Parts, by weight. |
|---|---|
| Wheat bran | 1 |
| Corn meal | 3 |
| Old process linseed meal | 3 |

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[1] Bulletin 74, Bureau of Animal Industry.

Timothy hay was continued as the coarse feed. While this change in the grain disturbs the comparison between the three years as regards the influence of age, it does not affect the comparison of the two animals with each other. Table 3 shows the rations fed.

TABLE 3.—*Daily rations in respiration calorimeter experiments.*

| Experiment. | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Timothy hay. | Wheat bran. | Corn meal. | Old-process linseed meal. | Timothy hay | Wheat bran. | Corn meal. | Old-process linseed meal |
| *Experiments of 1905.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Period I | 2.250 | 1,600 | ...... | ...... | 2,000 | 1,200 | ...... | ...... |
| Period II | 2,250 | 3,000 | ...... | ...... | 2,000 | 2,000 | ...... | ...... |
| Period III | 2,250 | ...... | ...... | ...... | 2,000 | ...... | ...... | ...... |
| Period IV | 4,000 | ...... | ...... | ...... | 3,000 | ...... | ...... | ...... |
| *Experiments of 1906.* | | | | | | | | |
| Period I | 3,000 | 300 | 900 | 900 | 2,800 | 200 | 600 | 600 |
| Period II | 3,000 | 700 | 2,100 | 2,100 | 2,800 | 357 | 1,072 | 1,071 |
| Period III | 3,000 | ...... | ...... | ...... | 2,800 | ...... | ...... | ...... |
| Period IV | 5,000 | ...... | ...... | ...... | 4,300 | ...... | ...... | ...... |
| *Experiments of 1907.* | | | | | | | | |
| Period I | 3,400 | 335 | 1,000 | 1,000 | 3,200 | 235 | 700 | 700 |
| Period II | 3,400 | 800 | 2,400 | 2,400 | 3,200 | 450 | 1,350 | 1,350 |
| Period III | 3,400 | ...... | ...... | ...... | 3,200 | ...... | ...... | ...... |
| Period IV | 5,600 | ...... | ...... | ...... | 5,300 | ...... | ...... | ...... |

## RELATIVE DIGESTIVE POWER.

As stated in the introduction, differences in the productive capacity of animals have been somewhat commonly ascribed to differences in digestive power. Do the results of this investigation support that view? The term "digestibility" has not infrequently been loosely used as equivalent to the total effect of the food upon growth, fattening, milk production, etc. In scientific usage, however, the conception of digestibility is, of course, entirely distinct from that of nutritive effect. The percentage digestibility means simply the proportion of the feeding stuff which the digestive organs of the animal are able to bring into solution and transmit to the blood for the various uses of the body. The nutritive effect obtained depends upon how good use the tissues of the body can make of materials thus supplied to them by the digestive organs. Digestibility is commonly determined by measuring the difference between feed and feces, the latter being regarded as consisting of the indigestible portion of the feed. While this is not strictly true in the case of farm animals it is sufficiently so for many purposes, while the difference does represent the net contribution of the feed to the nutrition of the body. In the present discussion the term "digested matter" is used as equivalent to "feed minus feces."

In comparing the digestive powers of two animals it is obviously necessary that they should receive identical rations, since feeds differ among themselves in digestibility. This condition is strictly fulfilled only in those of the calorimeter experiments in which hay was fed alone, and these will be first considered.

### DIGESTIBILITY OF HAY.

The hay used was, as previously stated, nearly pure timothy (*Phleum pratense*). Analyses of duplicate samples taken at the beginning of each season's experiments showed the dry matter of the hay to have had the composition recorded in Table 4. Examination of subsequent samples taken as the hay was weighed out for feeding fully confirmed the accuracy of the sampling.

TABLE 4.—*Composition of timothy hay*[1]*—water-free.*

| Component. | 1905 | 1906 | 1907 |
|---|---|---|---|
| | *Per cent.* | *Per cent.* | *Per cent* |
| Ash | 4.87 | 5.86 | 5.01 |
| Protein[2] | 5.08 | 6.72 | 6.90 |
| Nonprotein[2] | .39 | .83 | .24 |
| Crude fiber | 38.14 | 33.02 | 31.15 |
| Nitrogen-free extract | 49.51 | 51.01 | 54.55 |
| Ether extract | 2.01 | 2.56 | 2.15 |
| Total dry matter | 100.00 | 100.00 | 100.00 |
| Organic matter | 95.13 | 94.14 | 94.99 |
| Total nitrogen | .894 | 1.251 | 1.155 |
| Protein nitrogen | .812 | 1.075 | 1.104 |
| Carbon | 46.849 | [3] 46.803 | [3] 46.943 |
| Hydrogen | 6.302 | [3] 6.570 | [3] 5.779 |
| | *Calories.* | *Calories.* | *Calories.* |
| Energy per gram[4] | 4.4309 | 4.5159 | [3] 4.5053 |

[1] Average of two general samples.

[2] Computed from nitrogen, using the factors stated in Part III, page 203.

[3] Average of four samples weighed out for the four periods.

[4] The word "calorie" in this bulletin signifies in every instance the large, or kilogram, calorie.

As stated, two different amounts of hay were fed each year, one being slightly below (in one instance slightly above) the maintenance requirement and the other considerably below it. They are designated here for convenience as maintenance and submaintenance rations without implying that the former was an exact maintenance ration. The results of the digestion trials, which are recorded in Part II of this bulletin, are summarized in Table 5.

TABLE 5.—*Percentage digestibility of timothy hay.*

| Component. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Submaintenance. | Maintenance. | True average. | Submaintenance | Maintenance. | True average. |
| *Experiments of 1905.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Ash | 36.6 | 36.4 | 36.5 | 37.7 | 27.8 | 31.9 |
| Protein[1] | 23.2 | 8.5 | 14.4 | 10.1 | ........ | 3.0 |
| Crude fiber | 54.6 | 50.8 | 52.2 | 55.8 | 54.7 | 55.1 |
| Nitrogen-free extract | 59.0 | 57.5 | 58.0 | 60.0 | 61.4 | 60.8 |
| Ether extract | 44.5 | 45.1 | 44.9 | 46.3 | 53.1 | 50.5 |
| Total dry matter | 54.6 | 51.9 | 52.8 | 54.9 | 55.0 | 54.9 |
| Organic matter | 55.3 | 52.6 | 53.6 | 55.6 | 56.1 | 55.9 |
| Total nitrogen | 36.2 | 24.8 | 29.3 | 20.6 | 24.3 | 22.9 |
| Carbon | 51.4 | 49.1 | 49.9 | 51.9 | 52.3 | 52.2 |
| Organic hydrogen | 58.6 | 45.2 | 50.2 | 35.9 | 55.6 | 55.7 |
| Energy | 50.9 | 48.6 | 49.5 | 49.9 | 51.5 | 50.8 |
| *Experiments of 1906.* | | | | | | |
| Ash | 48.7 | 42.9 | 45.0 | 42.3 | 42.7 | 42.5 |
| Protein[1] | 31.8 | 35.4 | 34.1 | 35.3 | 36.1 | 35.8 |
| Crude fiber | 54.0 | 52.1 | 52.8 | 58.2 | 55.7 | 56.7 |
| Nitrogen-free extract | 58.9 | 57.3 | 57.9 | 59.8 | 58.1 | 58.8 |
| Ether extract | 47.6 | 49.1 | 48.6 | 43.4 | 52.4 | 49.1 |
| Total dry matter | 54.7 | 53.1 | 53.7 | 56.4 | 54.9 | 55.5 |
| Organic matter | 55.1 | 53.7 | 54.2 | 57.3 | 55.6 | 56.3 |
| Total nitrogen | 37.9 | 42.1 | 40.6 | 40.9 | 42.7 | 42.0 |
| Carbon | 53.0 | 51.0 | 51.7 | 54.4 | 52.1 | 53.0 |
| Organic hydrogen | 54.5 | 53.2 | 53.7 | 55.9 | 52.2 | 53.6 |
| Energy | 51.8 | 50.1 | 50.7 | 53.6 | 52.0 | 52.6 |
| *Experiments of 1907.* | | | | | | |
| Ash | 39.7 | 38.4 | 38.9 | 37.5 | 40.1 | 39.1 |
| Protein[1] | 40.9 | 45.5 | 43.8 | 43.0 | 44.0 | 43.6 |
| Crude fiber | 63.1 | 62.6 | 62.8 | 64.1 | 61.7 | 62.6 |
| Nitrogen-free extract | 67.0 | 65.5 | 66.1 | 65.5 | 64.9 | 65.1 |
| Ether extract | 47.3 | 48.4 | 48.0 | 44.4 | 50.7 | 48.4 |
| Total dry matter | 62.6 | 61.6 | 62.0 | 62.0 | 61.0 | 61.4 |
| Organic matter | 63.8 | 62.9 | 63.2 | 63.3 | 62.2 | 62.6 |
| Total nitrogen | 48.4 | 49.6 | 49.1 | 50.2 | 48.2 | 48.9 |
| Carbon | 60.5 | 59.6 | 59.9 | 59.8 | 59.2 | 59.4 |
| Organic hydrogen | 62.0 | 61.7 | 61.8 | 62.5 | 61.7 | 62.0 |
| Energy | 59.2 | 58.2 | 58.6 | 58.4 | 57.6 | 57.9 |

[1] Nonprotein assumed to be entirely digestible. Computed from nitrogen, using the factors stated in Part III, page 203.

### INFLUENCE OF AMOUNT OF HAY CONSUMED ON DIGESTIBILITY.

A comparison of the submaintenance and maintenance periods shows that the digestibility of the crude fiber was less in every instance, and that of the nitrogen-free extract in every case but one (that of steer B in the experiments of 1905) upon the heavier of the two rations. Since these two ingredients make up the bulk of the organic matter of the hay, the percentage digestibility found for the organic matter and for the total dry matter is likewise less on the heavier ration, with the exception noted; and the same is also true of the total carbon and the total energy. The differences are not large, their extreme range being:

| | Per cent. |
|---|---|
| Crude fiber | 0.5–3.8 |
| Nitrogen-free extract | .6–1.7 |
| Dry matter | 1.0–2.7 |
| Organic matter | 1.1–2.7 |
| Carbon | .6–2.3 |
| Energy | .8–2.3 |

In some cases the differences are decidedly less than the probable experimental error, while in no case are they considerable; but, nevertheless, their general uniformity of direction seems to indicate clearly a real, although slight, effect of increasing quantity in diminishing the percentage digestibility.

On the other hand, in four cases out of six the digestibility of the protein as here computed (i. e., assuming the nonprotein to be entirely digestible) was greater in the heavier ration, and the same is true of the total nitrogen, although the cases are not identical with those under protein.[1] The ether extract in all cases showed a higher digestibility in the heavier rations. The differences in digestibility of these ingredients are of about the same order of magnitude as those noted in the previous paragraph, except in the case of the ether extract in the experiments of 1907, where the difference was decidedly greater with steer B. It is not impossible that these apparent differences in the digestibility of nitrogenous materials and of ether extract may be due to a relatively lower amount of metabolic products in the feces from the heavier rations, while the method here adopted for computing the digestibility of the protein is not free from error. It was not found practicable, however, in these experiments to enter into any of the very interesting questions regarding the true as compared with the apparent digestibility of these nutrients.

### COMPARISON OF ANIMALS.

In making a comparison of the digestive powers of the two animals, the possible influence of differences in the amount of hay consumed must be borne in mind. Obviously, too, since the animals differed in weight, this is a question of relative and not of absolute consumption. Table 6 shows the average of the last six weighings of each animal in each period, the actual consumption of dry matter per head, and the same calculated per 500 kilograms live weight, first in direct proportion to the weight and, second, in proportion to the two-thirds power of the live weight. The latter, however, would appear to be the proper basis of comparison, since it may be assumed that the efficiency of the digestive and resorptive organs would be proportional to their internal surface rather than to their cubic capacity.

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[1] The results upon protein in the experiments of 1905 are obviously of questionable value.

TABLE 6.—*Dry matter of hay eaten.*

| Experiments. | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Live weight. | Dry matter of hay. | | | Live weight. | Dry matter of hay. | | |
| | | Per head. | Per 500 kilos. | | | Per head. | Per 500 kilos. | |
| | | | W. | $W^{\frac{3}{4}}$. | | | W. | $W^{\frac{3}{4}}$. |
| *Experiments of 1905.* | *Kilos.* | *Grams.* | *Grams.* | *Grams.* | *Kilos.* | *Grams.* | *Grams.* | *Grams.* |
| Submaintenance (Period III) | 268.8 | 2,001 | 3,722 | 3,026 | 194.1 | 1,774 | 4,570 | 3,334 |
| Maintenance (Period IV) | 277.5 | 3,493 | 6,294 | 5,172 | 189.6 | 2,610 | 6,884 | 4,980 |
| *Experiments of 1906.* | | | | | | | | |
| Submaintenance (Period III) | 399.1 | 2,647 | 3,316 | 3,076 | 296.2 | 2,470 | 4,169 | 3,501 |
| Maintenance (Period IV) | 406.6 | 4,425 | 5,442 | 5,079 | 308.6 | 3,805 | 6,162 | 5,249 |
| *Experiments of 1907.* | | | | | | | | |
| Submaintenance (Period III) | 507.3 | 2,974 | 2,931 | 2,945 | 373.7 | 2,798 | 3,744 | 3,398 |
| Maintenance (Period IV) | 514.2 | 4,892 | 4,757 | 4,801 | 384.9 | 4,630 | 6,015 | 5,513 |

From Table 6 it appears that, with the exception of the maintenance ration of 1905, steer B consumed in every case relatively more hay than steer A, so that any effect of the quantity of hay consumed would be to lower the digestibility by steer B. We actually find, on the contrary, a distinct tendency toward a higher digestibility by steer B in the first two years. This is true of the total dry matter, the organic matter, the crude fiber, the nitrogen-free extract, the carbon, and the energy, with but a single exception (the energy of the submaintenance ration in 1905). The differences show a range very similar to that observed in regard to the influence of quantity but are in the opposite direction, that is, while in five cases out of six steer B consumed relatively more dry matter than steer A, the percentage digestibility is greater on the part of steer B. The actual range of the differences is:

| | Per cent. |
|---|---|
| Crude fiber | 1.2–4.2 |
| Nitrogen-free extract | .9–3.9 |
| Dry matter | .3–3.1 |
| Organic matter | .3–3.5 |
| Carbon | .5–3.2 |
| Energy | 1.9–2.9 |

In the third season, 1907, on the contrary, steer A seems to have overtaken steer B as regards digestive power, the differences being in every case slightly in favor of steer A, although they are mostly fractions of 1 per cent, the results being practically identical. The results upon total nitrogen, protein, and ether extract are irregular and lead to no conclusions.

### INFLUENCE OF AGE OF ANIMALS.

The percentage digestibility appears to have increased from year to year in these experiments. A strict comparison is not possible, however, since the composition of the hay consumed was not identical in the three seasons. The hay of 1905 was low in nitrogen and high in crude fiber and had a correspondingly low digestibility. That of 1906 was of better quality, containing considerably less fiber, and shows a notably higher percentage digestibility of the total nitrogen and of the protein, but only a slight gain in that of the crude fiber and nitrogen-free extract. The hay of 1907 contained almost the same percentage of total nitrogen as that of the previous season but a larger proportion of true protein, and the digestibility of the latter again showed a marked increase. The most striking difference, however, is the notable increase in the percentage digestibility of the nonnitrogenous ingredients in 1907 as compared with 1906. This is true both of the crude fiber, the nitrogen-free extract, the total carbon, and the energy, as well as of the dry matter and total organic matter. While some of this difference may be due to the lower crude fiber content of the hay, it seems questionable whether it can all be ascribed to this cause. The figures at least suggest an influence of the age of the animal. If such is actually the explanation, the increase, as already noted, was apparently greater with steer A than with steer B, so that the digestive powers of the two animals appear practically equal in the third year.

All the differences just discussed are relatively small and the experiments as a whole are in accord with those of numerous previous investigators in showing that individual differences in digestive power are of comparatively little significance. At any rate the results as regards the hay clearly fail to show any superiority in this respect on the part of the purebred over the scrub animal, or on the part of the young over the more mature animal.

### DIGESTIBILITY OF GRAIN.

In the experiments of 1905 wheat bran constituted the exclusive grain ration. In the other two years the grain consisted of a mixture by weight of 1 part of bran, 3 of corn meal, and 3 of old process linseed meal. In 1905 two general samples of the bran were taken which agreed closely in composition with each other and also with subsequent samples taken in the course of the experiments. In the other two years each kind of grain was weighed out separately in the proportions given and the composition of the mixture computed, check analyses on the mixture agreeing substantially with the computed composition. Table 7 shows the average composition of the grain used in each season.

TABLE 7.—*Composition of grain—water-free.*

| Component. | Wheat bran, 1905. | Mixed grain, 1906. | Mixed grain, 1907. |
|---|---|---|---|
| | *Per cent.* | *Per cent.* | *Per cent.* |
| Ash | 7.52 | 4.10 | 4.14 |
| Protein[1] | 14.50 | 16.97 | 17.95 |
| Nonprotein[1] | .49 | 3.43 | 2.22 |
| Crude fiber | 11.49 | 6.10 | 6.16 |
| Nitrogen-free extract | 61.88 | 62.89 | 64.38 |
| Ether extract | 4.12 | 6.51 | 5.15 |
| | 100.00 | 100.00 | 100.00 |
| Organic matter | 92.48 | 95.90 | 95.86 |
| Total nitrogen | 2.648 | 3.743 | 3.658 |
| Protein nitrogen | 2.544 | 3.013 | 3.185 |
| Carbon | 46.392 | 46.860 | 46.957 |
| Hydrogen | 6.768 | 6.965 | 6.082 |
| Energy per gram | *Calories.*<br>4.5318 | *Calories.*<br>4.6904 | *Calories.*<br>4.6698 |

[1] Computed from nitrogen, using factors stated in Part III, page 203.

The digestibility of the grain must, of course, be estimated from that of the total ration by subtracting the amount computed to have been digested from the hay, and for well-known reasons the results of such a computation are subject to not inconsiderable errors. The first question which arises is what digestibility should be assumed for the hay in these experiments. On the one hand the hay portion of the mixed ration was substantially the same in amount as the hay fed in the submaintenance periods, so that it may seem that the coefficients obtained in those periods should be used. On the other hand, however, a considerable amount of grain was fed with the hay, so that the total amount of dry matter consumed was even greater than in the maintenance periods on hay. The matter is largely one of arbitrary choice, but fortunately the differences are not large. The experiments have been computed by the use of what may be called the true average digestibility. The amounts of each ingredient digested in the two experiments with the hay alone have been added and compared with the total amount of the same ingredient consumed, thus giving more weight to the maintenance than to the submaintenance periods. These averages are the ones recorded in Table 5, page 27. Two amounts of grain were fed each year along with practically the same quantity of hay. The detailed figures are given in Part II of this bulletin and the results as to percentage digestibility summarized in Table 8. For the sake of comparison there has been included in the table the percentage digestibility of the total crude fiber plus nitrogen-free extract, i. e., of the total nonnitrogenous organic matter other than ether extract.

TABLE 8.—*Percentage digestibility of grain.*

| Components. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Light ration. | Heavy ration. | Average. | Light ration. | Heavy ration. | Average. |
| *Experiments of 1905—Wheat bran.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Ash | 44.3 | 53.6 | 49.0 | 20.3 | 44.7 | 32.5 |
| Protein[1] | 72.2 | 73.2 | 72.7 | 76.9 | 85.8 | 81.4 |
| Crude fiber | 2.9 | 22.7 | 12.8 | 11.0 | 12.9 | 12.0 |
| Nitrogen-free extract | 74.1 | 74.4 | 74.3 | 75.0 | 77.0 | 76.0 |
| Ether extract | 82.3 | 81.0 | 86.7 | 70.9 | 77.0 | 74.0 |
| Total dry matter | 64.9 | 67.2 | 66.1 | 64.9 | 68.1 | 66.5 |
| Crude fiber+nitrogen-free extract | 63.6 | 66.4 | 65.0 | 65.3 | 67.8 | 66.6 |
| Organic matter | 66.5 | 68.3 | 67.4 | 67.7 | 70.1 | 68.9 |
| Total nitrogen | 74.7 | 75.9 | 75.3 | 78.7 | 81.5 | 80.1 |
| Carbon | 68.7 | 68.3 | 68.5 | 69.2 | 70.8 | 70.0 |
| Organic hydrogen | 79.2 | 73.1 | 76.2 | 71.0 | 72.8 | 71.9 |
| Energy | 67.3 | 67.6 | 67.5 | 67.8 | 70.4 | 69.1 |
| *Experiments of 1906—Mixed grain.* | | | | | | |
| Ash | 24.0 | 39.1 | 31.6 | 30.7 | 30.0 | 30.4 |
| Protein[1] | 78.9 | 66.2 | 72.6 | 81.2 | 71.0 | 76.0 |
| Crude fiber | 70.9 | − 7.3 | 31.8 | 38.9 | −56.9 | − 9.0 |
| Nitrogen-free extract | 90.6 | 87.8 | 89.2 | 91.7 | 89.0 | 90.4 |
| Ether extract | 104.1 | 95.0 | 99.6 | 108.3 | 99.9 | 104.1 |
| Total dry matter | 85.6 | 77.1 | 81.4 | 85.3 | 75.5 | 80.4 |
| Crude fiber+nitrogen-free extract | 88.8 | 79.2 | 84.0 | 86.9 | 75.8 | 81.3 |
| Organic matter | 88.3 | 78.7 | 83.5 | 87.6 | 77.4 | 82.5 |
| Total nitrogen | 84.7 | 75.6 | 80.2 | 86.2 | 79.3 | 82.8 |
| Carbon | 86.4 | 76.9 | 81.7 | 86.6 | 76.8 | 81.7 |
| Organic hydrogen | 92.9 | 77.0 | 85.0 | 99.2 | 77.8 | 88.5 |
| Energy | 87.0 | 77.6 | 82.3 | 86.4 | 77.3 | 81.9 |
| *Experiments of 1907—Mixed grain.* | | | | | | |
| Ash | 27.9 | 29.4 | 28.7 | 10.9 | 36.5 | 23.7 |
| Protein[1] | 73.9 | 73.0 | 73.4 | 81.7 | 78.8 | 80.3 |
| Crude fiber | 11.3 | − 7.2 | 2.1 | −13.9 | 17.6 | 1.9 |
| Nitrogen-free extract | 87.4 | 87.6 | 87.5 | 84.5 | 91.1 | 87.8 |
| Ether extract | 97.5 | 92.1 | 94.8 | 89.7 | 91.5 | 90.6 |
| Total dry matter | 78.4 | 77.2 | 77.8 | 75.2 | 82.3 | 78.8 |
| Crude fiber+nitrogen-free extract | 80.6 | 79.3 | 80.0 | 73.8 | 84.6 | 80.2 |
| Organic matter | 80.6 | 79.3 | 80.0 | 78.0 | 84.3 | 81.2 |
| Total nitrogen | 79.1 | 78.7 | 78.9 | 85.0 | 83.4 | 84.2 |
| Carbon | 78.7 | 77.9 | 78.3 | 75.9 | 83.4 | 79.6 |
| Organic hydrogen | 81.2 | 79.2 | 80.2 | 76.0 | 85.2 | 80.6 |
| Energy | 79.6 | 78.3 | 78.9 | 76.3 | 83.1 | 79.7 |

[1] Nonprotein assumed to be entirely digestible. Computed from nitrogen, using factors stated in Part III, page 203.

The negative coefficients for crude fiber shown in the foregoing table are familiar results of such computations of the digestibility of a grain ration and, of course, are to be interpreted as indicating that the grain diminished the digestibility of the crude fiber of the hay. These effects, even if small in themselves, when calculated upon the small absolute amount of crude fiber in the grain become relatively great. The results show the usual irregularities in the case of those ingredients which are present in relatively small amount and whose digestibility is most affected by the presence of metabolic products in the feces, viz, the ether extract and the protein.

### INFLUENCE OF AMOUNT OF GRAIN CONSUMED ON DIGESTIBILITY.

The two following tables show the amount of dry matter contained in the total ration (grain plus hay) and in the grain consumed in each period per head and per 500 kilograms live weight computed as in the case of the hay in Table 6. It will be seen that the total consumption on the light ration, when computed in proportion to the surface of the animal, was very uniform. The additional amount consumed on the heavy ration ranged from about 22 to 34 per cent, except in the case of steer A in the last two experiments, where it rose to over 50 per cent.

TABLE 9.—*Dry matter of total ration (hay and grain) eaten.*

| Ration. | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Live weight. | Dry matter of ration. | | | Live weight. | Dry matter of ration. | | |
| | | Per head. | Per 500 kilos. | | | Per head. | Per 500 kilos. | |
| | | | W. | $W^{\frac{2}{3}}$. | | | W. | $W^{\frac{2}{3}}$. |
| *Experiments of 1905—Bran.* | *Kilos.* | *Grams.* | *Grams.* | *Grams.* | *Kilos.* | *Grams.* | *Grams.* | *Grams.* |
| Light ration (Period I) | 270.7 | 3,348 | 6,184 | 5,049 | 198.6 | 2,803 | 7,057 | 5,188 |
| Heavy ration (Period II) | 279.1 | 4,579 | 8,204 | 6,763 | 196.9 | 3,582 | 9,098 | 6,666 |
| *Experiments of 1906—Mixed grain.* | | | | | | | | |
| Light ration (Period I) | 404.0 | 4,400 | 5,446 | 5,073 | 298.0 | 3,628 | 6,087 | 5,123 |
| Heavy ration (Period II) | 420.7 | 6,804 | 8,085 | 7,634 | 309.6 | 4,583 | 7,402 | 6,306 |
| *Experiments of 1907—Mixed grain.* | | | | | | | | |
| Light ration (Period I) | 498.6 | 4,931 | 4,945 | 4,941 | 372.6 | 4,157 | 5,571 | 5,055 |
| Heavy ration (Period II) | 518.7 | 7,708 | 7,430 | 7,521 | 386.4 | 5,451 | 7,054 | 6,471 |

TABLE 10.—*Dry matter of grain eaten.*

| Ration. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Per head. | Per 500 kilos. | | Per head. | Per 500 kilos. | |
| | | W. | $W^{\frac{2}{3}}$. | | W. | $W^{\frac{2}{3}}$. |
| *Experiments of 1905—Bran.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Light ration (Period I) | 1,370.2 | 2,531 | 2,066 | 1,032.5 | 2,600 | 1,911 |
| Heavy ration (Period II) | 2,583.2 | 4,628 | 3,816 | 1,802.6 | 4,578 | 3,355 |
| *Experiments of 1906—Mixed grain.* | | | | | | |
| Light ration (Period I) | 1,792.0 | 2,218 | 2,066 | 1,194.7 | 2,005 | 1,687 |
| Heavy ration (Period II) | 4,172.9 | 4,959 | 4,682 | 2,129.0 | 3,439 | 2,930 |
| *Experiments of 1907—Mixed grain.* | | | | | | |
| Light ration (Period I) | 1,996.2 | 2,003 | 2,001 | 1,397.8 | 1,876 | 1,700 |
| Heavy ration (Period II) | 4,759.0 | 4,588 | 4,644 | 2,676.9 | 3,464 | 3,178 |

The digestibility of the bran is seen to be greater on the heavier ration, with the exception of the ether extract, total carbon, and organic hydrogen in the case of steer A. The differences, however, are small and probably within the range of error of such experiments.

With the mixed grain fed in 1906 and 1907 the results are contradictory. In the first year the digestibility appears to have been decidedly less on the heavier ration, while in 1907, on the other hand, very little difference is noted in the case of steer A, and in the case of steer B a notably higher digestibility is shown for the heavier ration. There is no apparent error in the determination of the digestibility of the total ration, but it is not easy to form a judgment as to the range of possible error in the computation of the digestibility of the grain from that of the total ration. The figures for the digestibility of the light ration in 1906 seem abnormally high as compared with the average digestion coefficients of these feeding stuffs, from which an average percentage digestibility of about 81 for the total dry matter of the mixed grain may be computed. On the whole, the safest course seems to be to consider that the average of the coefficients for the light and heavy rations represents approximately the actual digestibility of the grain.

### COMPARISON OF ANIMALS.

If we are justified in assuming, as just suggested, that the average figures for the two periods represent the true digestibility of the grain, very little difference appears between the two animals in this respect either in the case of the mixed grain or of the bran. If anything, the tendency is toward a slightly higher digestibility by steer B, but all the differences are much less than those found between the light and heavy rations.

### INFLUENCE OF AGE OF ANIMALS.

No comparison in this respect is possible between the experiments of the first year and those of the succeeding two, since the feed was different. The digestibility in the experiments of 1907 was, on the average, less than that found in the experiments of 1906, although again the differences are smaller than those found between the light and heavy rations. If we are justified in suspecting that the results obtained for the light ration in the experiments of 1906 are too high, the difference between the two animals in the two years becomes insignificant.

## PERCENTAGE OF ENERGY METABOLIZABLE.

By metabolizable energy is understood that portion of the total potential energy of the feed which is capable of conversion into kinetic energy in the body. Expressed in another way, it is the total potential energy of the feed minus the potential energy of the excreta, the latter including the feces, urine, and methane or other combustible gases. The determination of the percentage of the feed energy metabolized is precisely similar to the determination of the digestibility of the feed in being a determination by difference, the only distinction in this respect being that in the one case only one excretum (the feces) is taken account of, while in the other all the excreta are considered. The percentage of energy metabolizable may be computed either upon the total potential energy of the feed or upon the potential energy of the digested matter, the latter method of expression having the advantage for some purposes of eliminating the effect of variations in digestibility. The results for metabolizable energy are given in detail in Part II of this bulletin and are summarized here. As in the case of the determination of digestibility, it is necessary to consider first the results upon the hay, and with these as a basis to compute the corresponding results for the grain.

### TIMOTHY HAY.

The percentage losses of potential energy in the feces are of course the complements of the percentage digestibility as already given. The percentage losses in the urine and methane and the percentage of energy metabolizable are shown in Table 11.

TABLE 11.—*Percentage losses and percentages of energy metabolizable—Timothy hay.*

| | Per cent of total energy. | | | Per cent of "digested" energy. | | |
|---|---|---|---|---|---|---|
| | Submaintenance. | Maintenance. | True average. | Submaintenance. | Maintenance. | True average. |
| *Percentage losses of energy in urine.* | | | | | | |
| Experiments of 1905: | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Steer A | 3.64 | 2.86 | 3.14 | 7.15 | 5.88 | 6.35 |
| Steer B | 3.20 | 2.79 | 2.95 | 6.42 | 5.42 | 5.81 |
| Average | 3.42 | 2.83 | 3.05 | 6.79 | 5.65 | 6.08 |
| Experiments of 1906: | | | | | | |
| Steer A | 3.44 | 3.40 | 3.42 | 6.64 | 6.74 | 6.74 |
| Steer B | 3.72 | 3.70 | 3.71 | 6.94 | 7.12 | 7.05 |
| Average | 3.58 | 3.55 | 3.57 | 6.79 | 6.93 | 6.90 |
| Experiments of 1907: | | | | | | |
| Steer A | 4.52 | 4.40 | 4.45 | 7.64 | 7.56 | 7.60 |
| Steer B | 4.97 | 4.61 | 4.74 | 8.51 | 8.01 | 8.19 |
| Average | 4.75 | 4.51 | 4.60 | 8.08 | 7.79 | 7.90 |
| *Percentage losses of energy in methane.* | | | | | | |
| Experiments of 1905: | | | | | | |
| Steer A | 6.87 | 6.75 | 6.80 | 13.49 | 13.88 | 13.74 |
| Steer B | 7.76 | 6.78 | 7.17 | 15.56 | 13.17 | 14.12 |
| Average | 7.32 | 6.77 | 6.99 | 14.53 | 13.53 | 13.93 |
| Experiments of 1906 (computed from digested carbohydrates): | | | | | | |
| Steer A | 6.97 | 6.68 | 6.78 | 13.46 | 13.34 | 13.38 |
| Steer B | 7.24 | 6.92 | 7.04 | 13.51 | 13.30 | 13.38 |
| Average | 7.11 | 6.80 | 6.91 | 13.49 | 13.32 | 13.38 |
| Experiments of 1907: | | | | | | |
| Steer A | 8.17 | 7.90 | 8.00 | 13.81 | 13.57 | 13.65 |
| Steer B | 8.38 | 7.84 | 8.04 | 14.34 | 13.61 | 13.89 |
| Average | 8.28 | 7.87 | 8.02 | 14.08 | 13.59 | 13.77 |
| *Percentage of energy metabolizable.* | | | | | | |
| Experiments of 1905: | | | | | | |
| Steer A | 40.43 | 39.01 | 39.52 | 79.36 | 80.24 | 79.91 |
| Steer B | 38.92 | 41.88 | 40.70 | 78.02 | 81.41 | 80.07 |
| Average | 39.68 | 40.45 | 40.11 | 78.69 | 80.83 | 79.99 |
| Experiments of 1906: | | | | | | |
| Steer A | 41.37 | 40.01 | 40.52 | 79.90 | 79.87 | 79.88 |
| Steer B | 42.65 | 41.38 | 41.88 | 79.55 | 79.58 | 79.57 |
| Average | 42.01 | 40.70 | 41.20 | 79.73 | 79.73 | 79.73 |
| Experiments of 1907: | | | | | | |
| Steer A | 46.49 | 45.93 | 46.14 | 78.55 | 78.87 | 78.75 |
| Steer B | 45.07 | 45.13 | 45.11 | 77.15 | 78.38 | 77.92 |
| Average | 45.78 | 45.53 | 45.63 | 77.85 | 78.63 | 78.34 |

In consequence of the relatively smaller losses in the feces (i. e., the greater digestibility) observed in 1907, the percentage of the total energy of the hay which was metabolizable was higher than in the two previous years, the average percentages for both animals being:

*Percentage of total energy metabolizable.*

| | Per cent. |
|---|---|
| Experiment of 1905 | 40.11 |
| Experiment of 1906 | 41.20 |
| Experiment of 1907 | 45.63 |

When the influence of varying digestibility is eliminated by computing the percentage of "digested" energy metabolizable, this difference practically disappears, the results being:

*Percentage of "digested" energy metabolizable.*

| | Per cent. |
|---|---|
| Experiment of 1905 | 79.99 |
| Experiment of 1906 | 79.73 |
| Experiment of 1907 | 78.34 |

Computed in this way, the percentage of the "digested" energy which was metabolizable shows a slight decrease from year to year which is chiefly due to an increasing percentage loss in the urine. The latter, however, may be plausibly accounted for by the greater richness of the hay in protein, especially in 1907. If this explanation be accepted, the experiments fail to give any indication of an influence of the age of the animal upon the percentage of energy metabolizable.

But very little difference is apparent between the two animals as respects the percentage of energy metabolizable. Averaging the results on the two animals for the three years we have the following:

TABLE 12.—*Percentage of energy of timothy hay metabolizable—Average of 3 years.*

| | Submaintenance ration. | Maintenance ration. | Average. |
|---|---|---|---|
| Total energy: | *Per cent.* | *Per cent.* | *Per cent.* |
| Steer A | 42.76 | 41.65 | 42.06 |
| Steer B | 42.21 | 42.80 | 42.56 |
| "Digested" energy: | | | |
| Steer A | 79.27 | 79.66 | 79.51 |
| Steer B | 78.24 | 79.79 | 79.19 |

Neither does the amount of hay consumed appear to have had any material influence, except possibly in the case of steer B, where a slightly greater loss both in the urine and the methane is recorded in the submaintenance periods. The differences, however, hardly seem significant.

### GRAIN.

The data for the grain, as already noted, must be computed by difference and therefore are subject, like the results of a digestion experiment, to relatively large errors. The percentage losses in urine and methane and the percentages of energy metabolizable are summarized in Table 13.

TABLE 13.—*Percentage losses and percentages of energy metabolizable—Grain.*

| | Per cent of total energy. | | | Per cent of "digested" energy. | | |
|---|---|---|---|---|---|---|
| | Submaintenance. | Maintenance. | Average. | Submaintenance. | Maintenance. | Average. |
| *Percentage losses of energy in urine.* | | | | | | |
| Experiments of 1905—Bran: | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Steer A | 5.06 | 4.90 | 4.98 | 7.51 | 7.25 | 7.38 |
| Steer B | 5.52 | 6.04 | 5.78 | 8.14 | 8.57 | 8.36 |
| Average | 5.29 | 5.47 | 5.38 | 7.83 | 7.91 | 7.87 |
| Experiments of 1906—Mixed grain: | | | | | | |
| Steer A | 7.62 | 6.13 | 6.88 | 8.76 | 7.90 | 8.33 |
| Steer B | 8.19 | 6.86 | 7.53 | 9.48 | 8.89 | 9.19 |
| Average | 7.91 | 6.50 | 7.21 | 9.12 | 8.40 | 8.76 |
| Experiments of 1907—Mixed grain: | | | | | | |
| Steer A | 6.78 | 6.28 | 6.53 | 8.52 | 8.02 | 8.27 |
| Steer B | 7.79 | 7.53 | 7.66 | 10.21 | 9.06 | 9.64 |
| Average | 7.29 | 6.91 | 7.10 | 9.37 | 8.54 | 8.96 |
| *Percentage losses of energy in methane* | | | | | | |
| Experiments of 1905—Bran: | | | | | | |
| Steer A | 8.04 | 6.93 | 7.49 | 11.94 | 10.25 | 11.10 |
| Steer B | 7.18 | 7.56 | 7.37 | 10.58 | 10.73 | 10.66 |
| Average | 7.61 | 7.25 | 7.43 | 11.26 | 10.49 | 10.88 |
| Experiments of 1906—Mixed grain:[1] | | | | | | |
| Steer A | 8.30 | 7.63 | 7.97 | 9.54 | 9.83 | 9.69 |
| Steer B | 8.11 | 7.30 | 7.71 | 9.38 | 9.44 | 9.41 |
| Average | 8.21 | 7.47 | 7.84 | 9.46 | 9.64 | 9.55 |
| Experiments of 1907—Mixed grain: | | | | | | |
| Steer A | 8.52 | 7.29 | 7.91 | 10.70 | 9.31 | 10.01 |
| Steer B | 9.42 | 8.72 | 9.07 | 12.35 | 10.48 | 11.42 |
| Average | 8.97 | 8.01 | 8.49 | 11.53 | 9.90 | 10.72 |
| *Percentage of energy metabolizable.* | | | | | | |
| Experiments of 1905—Bran: | | | | | | |
| Steer A | 54.24 | 55.77 | 55.01 | 80.55 | 82.50 | 81.53 |
| Steer B | 55.13 | 56.85 | 55.99 | 81.24 | 80.70 | 80.97 |
| Average | 54.69 | 56.31 | 55.50 | 80.90 | 81.60 | 81.25 |
| Experiments of 1906—Mixed grain: | | | | | | |
| Steer A | 71.08 | 63.86 | 67.47 | 81.70 | 82.27 | 81.99 |
| Steer B | 70.10 | 63.18 | 66.64 | 81.14 | 81.67 | 81.41 |
| Average | 70.59 | 63.52 | 67.06 | 81.42 | 81.97 | 81.70 |
| Experiments of 1907—Mixed grain: | | | | | | |
| Steer A | 64.28 | 64.70 | 64.49 | 80.78 | 82.67 | 81.73 |
| Steer B | 59.08 | 66.88 | 62.98 | 77.44 | 80.46 | 78.95 |
| Average | 61.68 | 65.79 | 63.74 | 79.11 | 81.57 | 80.34 |

[1] Computed from digested carbohydrates.

The greater digestibility of the mixed grain used in the second and third years as compared with that of the bran fed during the first year of course raises the percentage of the total energy metabolizable in the two latter years, the average results for the two animals being:

*Percentage of total energy metabolizable.*

| | Per cent. |
|---|---|
| Experiment cf 1905 (wheat bran) | 55.50 |
| Experiment of 1906 (mixed grain) | 67.06 |
| Experiment of 1907 (mixed grain) | 63.74 |

As between the second and third years, the lower digestibility of the grain observed in 1907, of course, lowers correspondingly the percentage of the total energy metabolized. When, however, we eliminate the influence of the digestibility, by computing the results upon the "digested" energy, we obtain almost uniform results for the three years. The slightly lower figure for the last year is due, as in the case of the hay, to a slightly greater relative loss in the urine.

*Percentage of "digested" energy metabolizable.*

| | Per cent. |
|---|---|
| Experiment of 1905 (wheat bran) | 81.25 |
| Experiment of 1906 (mixed grain) | 81.70 |
| Experiment of 1907 (mixed grain) | 80.34 |

The percentage of "digested" energy metabolizable appears to have been slightly greater on the heavy than on the light ration, the difference being due to somewhat smaller losses in the methane. It is questionable, however, whether any of these differences are sufficiently large to be significant.

On the average of the results of all three years, disregarding the differences of feed in the first year, steer A shows a slight superiority over steer B in the percentage of energy metabolizable. This difference is largely due, however, to the comparatively low result obtained for steer B on the light ration of 1907. Except for this, the differences are very small and doubtless within the limits of error.

TABLE 14.—*Percentage of energy of grain metabolizable—Average of 3 years.*

| | Light ration. | Heavy ration. | Average. |
|---|---|---|---|
| Total energy: | *Per cent.* | *Per cent.* | *Per cent.* |
| Steer A | 63.20 | 61.44 | 62.32 |
| Steer B | 61.44 | 62.30 | 61.87 |
| "Digested" energy: | | | |
| Steer A | 81.01 | 82.48 | 81.75 |
| Steer B | 79.94 | 80.94 | 80.44 |

On the whole, the results for metabolizable energy agree closely with those obtained regarding the digestibility of the feed and fail to indicate with certainty any effect of age or of individuality upon either. This is quite what would have been expected and, so far as digestibility is concerned, is in accord with the results of other investigators. The process of digestion might be called, in a broad way, a chemical process. In healthy animals under normal conditions and after they have passed the stage of extreme youth, we may assume that the digestive enzyms are secreted in quantity sufficient to secure complete action upon all the food ingredients consumed, unless these are taken in excessive quantities. Furthermore, it may be assumed that by the time cattle have reached the age of 8 or 10 months a normal bacteriological flora has been established in the digestive tract. Under these conditions digestion may be said to be a chemical and bacteriological rather than a physiological process. It is a sort of incubation of materials which have not yet, strictly speaking, entered into the substance of the body at all. Under such conditions there is little scope for any effect of age or of individuality.

### AVAILABILITY OF METABOLIZABLE ENERGY.

The metabolizable energy of a feeding stuff is that portion of its total potential energy which is capable of conversion into the kinetic form in the body. It corresponds to the conception of "Physiologischer Wärmewert," or "Physiologischer Nutzeffekt," introduced by Rubner[1] in connection with his experiments upon the replacement values of nutrients, or to the fuel values of Atwater.[2] Upon the results of these earlier experiments Rubner based his celebrated law of isodynamic replacement. This law is in effect that, when fed in limited quantities, the several nutrients may be substituted as sources of energy for body substances previously katabolized, or may replace each other, in amounts inversely proportional to their physiological heat values, or metabolizable energy. The validity of this law was generally accepted and not only were the relative values of single nutrients and of human dietaries estimated upon the basis of their metabolizable energy, but it was attempted also to apply Rubner's factors to the digestible protein, carbohydrates, and fats, so-called, of stock feeds and extensive tables of the fuel values of the latter computed in this way have been published. Moreover, there was a natural tendency to overlook the limitation which Rubner set to his law and to apply it to productive as well as to maintenance rations.

It has been clearly demonstrated, however, that only under special conditions is the metabolizable energy, or fuel value, of a nutrient or feeding stuff the measure of its value to the organism. This was shown clearly by the early experiments of Zuntz and his associates, which antedate Rubner's results, while later investigations have fully confirmed the earlier ones, the difference being especially marked in the case of herbivorous animals. Zuntz and Hagemann[3] have demonstrated that this is the case with the horse, especially upon the coarse feeds; Kellner[1] has shown the same thing to hold true in the fattening of cattle; we[2] have demonstrated that it also holds in the case of maintenance and submaintenance rations of cattle; and Rubner[3] himself has shown that his earlier results were due to the comparatively low temperatures at which he experimented and constituted a special case of a general law.

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[1] Zeitschrift für Biologie; 21, 250 and 337.

[2] U. S. Dept. of Agr., Office of Experiment Stations Bul. 21; Conn, (Storrs) Experiment Station, 12th Report (1899), p. 71.

[3] Landw. Jahrb., 18, 1; 23, 125; 27, Ergänzbd. III.

Opinions are still more or less divided as to the cause of the phenomenon, but there is no dispute as to the fact. Only a part of the metabolizable energy of the food is ordinarily substituted for energy previously derived from the katabolism of protein and fat in the body or is recovered in the gain of flesh and fat made by the body on abundant feeding.

### METHOD OF DETERMINING AVAILABILITY.

The relation between the amount of metabolizable energy supplied to the animal in its feed and the resulting effect upon the body may be determined by a comparison of two periods in which different amounts of the feeding stuff or ration in question are consumed. For example, in Periods III and IV of the experiments of 1905 two different amounts of the same timothy hay were fed. After making the necessary corrections as described in succeeding paragraphs and in the detailed account of the experiments, it was found that the metabolizable energy of the rations consumed by steer A and the gain of energy by the animal (a loss being regarded as a negative gain) were as follows:

| | Metabolizable energy of ration. | Gain of energy by animal. |
|---|---|---|
| | *Calories.* | *Calories.* |
| Period IV | 5,981.4 | − 680.2 |
| Period III | 3,641.4 | −2,096.1 |
| Difference | 2,340.0 | 1,415.9 |

The excess of 2,340 calories of metabolizable energy in Period IV as compared with Period III reduced the loss of potential energy from the body by only 1,415.9 calories. In other words, only 60.5 per cent of the additional metabolizable energy supplied in Period IV was substituted for energy previously derived from the katabolism of body substance, while the remainder was disposed of by an increase of 924.1 calories in the heat production of the steer, corresponding to Rubner's "specific dynamic effect," the heat production rising from 5,635.8 calories to 6,559.9 calories (corrected). It is customary in such a case to speak of the 1,415.9 calories as the available energy of the hay added to the basal ration of Period III and to say that 60.5 per cent of the metabolizable energy of the hay was available. Such a method of statement does not necessarily imply that the remaining 39.5 per cent served no useful function in the body, but simply asserts that the net result to the organism was the same as if 60.5 per cent of the metabolizable energy were substituted unit for unit for energy derived from the katabolism of body substance and as if the remaining 39.5 per cent were useless. What the experiment really shows is that a unit of metabolizable energy in the hay had only 60.5 per cent of the value of a unit of metabolizable energy in the body substance (chiefly fat) previously katabolized, but the first method of expression is both common and convenient and may be retained. A precisely similar computation might, of course, be made, based upon the total instead of the metabolizable energy of the rations.

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[1] Landw. Vers. Stat., **44**, 257; **47**, 275; **50**, 245; **53**, 1.

[2] Bureau of Animal Industry Bulletins 51, 74, and 101; Landw. Jahrb., **32**, 665; **34**, 861; **37**, 423.

[3] Gesetze des Energieverbrauchs bei der Ernährung, 1902.

### CORRECTIONS.

In a determination of the availability of feed energy it is, of course, essential that the two periods compared be identical, except as to the amount of feed consumed. In practice it is impossible to secure exact identity, and certain corrections usually become necessary. These are, in the order of their importance, a correction for the influence of standing and lying, a correction for the difference in the live weight of the animal, and a correction for unavoidable variations in the amount of the basal ration consumed.

*Correction for standing and lying.*—The authors have shown in previous experiments that standing as compared with lying causes a very material increase in the metabolism of cattle. These results were fully confirmed in the present investigation. By averaging those portions of each period which seemed free from irregularities due to the change from the standing to the lying position, and vice versa, with its accompanying change in the rate of flow of water through the heat absorbers, and which also seemed free from accidental irregularities, the average rate per minute at which heat was emitted by the animal by means of radiation and conduction and brought out of the calorimeter in the water current was computed for the standing and lying positions separately. The method is described in detail in Part II of this bulletin, in connection with the experiments of 1905 (p. 118), and the results are given in full in connection with the experiments of each of the three years. The percentage excess of heat given off in the standing as compared with the lying position was found to be as shown in Table 15, the percentage being calculated upon the amount given off while lying. The figures of the table render it obvious that any considerable difference in the proportion of time spent standing or lying in the two periods to be compared would seriously distort the result.

TABLE 15.—*Percentage increase in heat emission due to standing.*

| | Experiments of 1905. | Experiments of 1906. | Experiments of 1907. |
|---|---|---|---|
| Steer A: | *Per cent.* | *Per cent.* | *Per cent* |
| Period I | 50.0 | 34.2 | 31.3 |
| Period II | 37.9 | 44.4 | 48.5 |
| Period III | 48.3 | 32.9 | 34.6 |
| Period IV | 36.3 | 41.6 | 37.2 |
| Steer B: | | | |
| Period I | 31.8 | 38.5 | 39.7 |
| Period II | 36.0 | 44.4 | 50.1 |
| Period III | 43.6 | 40.1 | 36.6 |
| Period IV | 36.9 | 42.0 | 46.4 |

In a recent article[1] Zuntz has called attention to the apparently smaller influence of standing and lying upon the metabolism of the sheep, as computed from experiments by Hagemann,[2] in which the difference in the heat production as computed from the respiratory exchange was only 8 per cent. Dahm,[3] working in Zuntz's laboratory and by his methods, likewise found an increase of only 8 per cent in the respiratory excretion of carbon dioxide by a young bull when standing as compared with that when lying. Zuntz points out that even with a uniform rate of heat production the heat emission would tend to be less in the lying posture, since less of the animal's surface is exposed for radiation and evaporation. Zuntz is inclined to attribute the discrepancy between our results and those of Hagemann and of Dahm to this effect, or, in other words, to assume in our experiments a storing up of heat, either in the body of the animal or in the platform beneath him, during the periods of lying.

That there would be a tendency in this direction is undeniable, but we do not believe that it is of sufficient magnitude to seriously affect our comparison of the metabolism standing and lying. While it is impracticable at this time to enter into a detailed discussion of the point, we hope to do so on another occasion, but attention may be called to the fact that in making the comparisons contained in Table 15 those portions of the experiments immediately preceding or following the change from the one position to the other were excluded.

The foregoing results refer only to that part of the heat which was given off by radiation and conduction and taken up by the water current in the heat absorbers. No similar results are available for that portion of the heat which was given off as latent heat of water vapor, since only the total elimination of this substance during each subperiod of 12 hours was determined. A comparison[4] of the proportion of the total heat evolved which was given off as latent heat of water vapor in the 96 subperiods of the three years, however, fails to afford any indication that this proportion was affected by the proportion of time spent standing or lying, although the latter varied quite widely. Consequently it has been assumed that the amount of heat given off as latent heat of water vapor is proportional to that given off by radiation and conduction. On this basis the heat production of each period has been corrected to what it would have been had the animal stood for 12 hours out of each 24. The method of computing the correction may be conveniently illustrated by the results on steer A in Period I of the experiments of 1905, for which the following data are recorded:

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[1] Medizinische Klinik, 1910.

[2] Arch. (Anat. u.) Physiol., 1899, Suppl., p. 111.

[3] Biochem. Ztsch., 28, 494.

[4] The details of the comparison will be found on pages 122-124 of Part II of this bulletin.

| | | |
|---|---|---|
| Heat emission per day: | | |
| By radiation and conduction | calories | 5,217.6 |
| As latent heat of water vapor | do | 3,293.8 |
| Total | do | 8,511.4 |
| Percentage of heat in water vapor | | 38.70 |
| Time standing | minutes | 1,137 |
| Time lying | do | 303 |
| Heat by radiation and conduction, per minute: | | |
| Standing | calories | 3.8260 |
| Lying | do | 2.5509 |
| Difference | do | 1.2751 |

If we multiply the difference between the heat emission per minute when standing and when lying by one-half the difference in the number of minutes standing and lying, we obtain a correction which in this case must be subtracted from the observed heat to obtain the heat computed to 12 hours standing, as follows:

$$1.2751 \times 417 = 531.7 \text{ calories.}$$
$$5{,}217.2 - 531.7 = 4{,}685.9 \text{ calories.}$$

Assuming that the percentage of the total heat emitted which was given off by radiation and conduction would have remained the same, viz, 61.30 per cent, the total heat emission would have been:

$$4{,}685.9 \div 0.6130 = 7{,}644.8 \text{ calories.}$$

The corrected heat emission as thus computed has been used in calculating the gain or loss of energy by the body. The balances of energy as thus corrected and the corresponding gains are recorded in Part II of this bulletin in connection with each of the three series of experiments (pp. 126, 157, and 184).

*Correction for live weight.*—The varying rations consumed caused greater or less changes in the live weights of the animals, which presumably caused corresponding changes in their maintenance requirements. It is evident, however, that if the steer weighs more in the second period than in the first some of the feed added in the second period will be used to supply his increased maintenance requirement, and in this way the comparison between the two periods will be disturbed. The method used for correcting this error may be conveniently illustrated by the results obtained with steer A in Periods III and IV in the experiments of 1905, which have already served (p. 40) to illustrate the general method of determining availability. The basis of the correction is the assumption that the maintenance requirement, as measured by the fasting katabolism, is approximately proportional to the two-thirds power of the live weight. This has been shown by various experimenters to be the case, not only with different animals of the same species but even with different species. According to Kellner, it is true, the increase in the maintenance requirement during fattening is in a somewhat more rapid proportion, but for the rather small changes in weight in these experiments and for the purpose of computing a correction simply the assumption is probably sufficiently accurate.

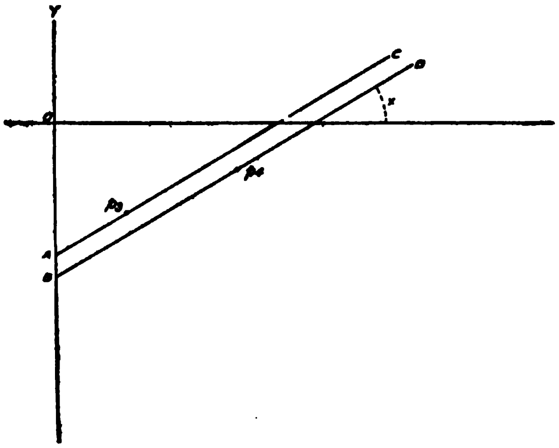

FIG. 6.—Correction for live weight.

In the periods selected as an illustration, the average of the last six weighings of steer A was: Period III, 268.8 kilograms; Period IV, 277.5 kilograms.

Assuming the fasting katabolism to be approximately proportional to the two-thirds power of the live weight, that of Period IV would be to that of Period III as 1 : 0.9781. In figure 6, in which the abscissas represent the metabolizable energy of the ration and the ordinates the gain of energy by the body, let the points $p_3$ and $p_4$ having the ordinates $x_3 y_3$ and $x_4 y_4$, respectively, represent the results obtained in Periods III and IV on the same animal. Through these points let there pass the parallel lines AC and BD, making with the axis of X the angle $x$, whose tangent would represent the percentage availability of the metabolizable energy of the hay. The distances OA and OB would then represent the fasting katabolism in the two periods and would be to each other as the two-thirds powers of the live weights. Letting $\frac{\mathrm{OA}}{\mathrm{OB}}=n$, and tang $x=m$, it may be shown that the value of $m$, that is, the availability of the metabolizable energy, is

$$m=\frac{y_3-ny_4}{x_3-nx_4}$$

Substituting the corresponding numerical values for steer A from Table 101, page 126, in Part II, viz,

$$x_3 = 3{,}641.4 \qquad y_3 = -2{,}096.1$$
$$x_4 = 6{,}115.3 \qquad y_4 = -\ \ 695.4$$
$$n = 0.9781$$

we find the percentage availability to be 60.51 per cent, as the following computation shows:

$$m = \frac{-2{,}096.1 - (0.9781 \times -695.4)}{3{,}641.4 - (0.9781 \times 6{,}115.3)} = 0.6051$$

*Correction for variations in basal ration.*—The availability of the energy of the grain is computed by comparison of a period in which both grain and hay were fed with a basal ration of hay alone. Such a comparison, of course, requires that the amount of hay consumed in each instance be the same, a condition which it is practically impossible to exactly fulfill.

The method of correction may be illustrated by the results upon steer A in Periods I and III of the experiments of 1905. The hay in Period I was intended to be the same in amount as in Period III, in which the basal ration was fed. On account of slight variations in the moisture content of the hay, however, the actual amounts of organic matter of hay consumed in the two periods varied slightly, so that the difference in metabolizable energy between the total rations of Periods I and III does not accurately represent the additional metabolizable energy derived from the bran. The total organic matter of the hay consumed was: In period III, 1,919.6 grams; in Period I, 1,894.3 grams; difference, 25.3 grams.

In the case of steer A, according to Table 94 of Part II (p. 116), the total organic matter of the hay contained, on the average of Periods III and IV, 1.853 calories of metabolizable energy per gram, of which 60.51 per cent, as just computed, was available. Applying these factors to the difference in the organic matter consumed in the hay, we may correct the results on Period I to what they would have been had the same amount of hay been consumed as in Period III, as follows:

| | Organic matter of hay consumed. | Metabolizable energy of total ration (Table 101). | Gain by body (Table 101). |
|---|---|---|---|
| | *Grams.* | *Calories.* | *Calories.* |
| In Period I | 1,894.3 | 6,889.1 | −951.3 |
| Correction for hay | +25.3 | +46.9 | + 28.4 |
| Period I, corrected | 1,919.6 | 6,936.0 | −922.9 |

The corrected results of Period I may then be compared with those of Period III, making a further correction for the difference in live weight in the same manner as in comparing Periods III and IV.

The average weight of the steer for the last six weighings of each of these periods was: Period III, 268.8 kilograms; Period I, 270.7 kilograms. The ratio of the fasting katabolism of Period III to that of Period I, represented by $n$ in the previous formula, would therefore be:

$$n=\left(\frac{268.8}{270.7}\right)^{2/3}=0.9951$$

The corresponding values of $x$ and $y$, after correction for the difference in the hay consumed, would be:

$$x_1=6{,}936.0 \qquad y_1=-\ \ 922.9$$
$$x_3=3{,}641.4 \qquad y_3=-2{,}096.1$$

Accordingly, the percentage availability, computed by the previous formula, is 36.11, the computation being as follows:

$$m=\frac{-2{,}096.1-(0.9951\times-922.9)}{3{,}641.4-(0.9951\times 6{,}936.0)}=0.3611$$

### PERCENTAGE AVAILABILITY.

The availability of the metabolizable energy in the several experiments has been computed in the manner above illustrated. The data for the several corrections, as well as the details of the computation, are recorded in connection with the description of the individual calorimeter experiments in Part II and the final results are summarized in Table 16.

TABLE 16.—*Percentage availability of metabolizable energy.*

| Ration. | 1905 | | 1906 | | 1907 | |
|---|---|---|---|---|---|---|
| | Steer A. | Steer B. | Steer A. | Steer B. | Steer A. | Steer B. |
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Timothy hay | 60.51 | 55.21 | 71.49 | 60.86 | 57.05 | 56.50 |
| Wheat bran: | | | | | | |
| Periods II-III | 58.74 | 51.98 | | | | |
| Periods I-III | 36.11 | 53.10 | | | | |
| Periods II-I | 84.13 | 50.55 | | | | |
| Mixed grain: | | | | | | |
| Periods II-III | | | 58.89 | 51.51 | 61.55 | 57.71 |
| Periods I-III | | | 74.02 | 41.12 | 58.18 | 58.73 |
| Periods II-I | | | 52.30 | 70.44 | 64.10 | 56.74 |

The foregoing results are also represented graphically in figures 7, 8, and 9, in which the abscissas represent the amounts of metabolizable energy in the several rations and the ordinates the corresponding gains of energy by the animal. The values for the several periods are those obtained after correcting for differences in live weight and in the amount of hay consumed. The percentage availability derived from a comparison of any two periods is equal, of course, to the tangent of the angle made by the corresponding line with the horizontal axis.

An inspection of the table and diagrams renders it evident that the results of the experiments of 1907, in which the closest agreement between the observed and computed heat production was obtained, are likewise the most consistent among themselves, while those of the two previous years show greater irregularities. The latter is especially the case with regard to the availability of the energy of the grain as computed respectively by a comparison of Periods I and III and of Periods II and I. On the other hand, if we regard Period III as the basal ration and compute the availability of the energy of the grain from a comparison of Periods II and III, the results in the three years are decidedly more concordant. Accordingly, in the figures the availability of the energy of the hay as shown by a comparison of Periods IV and III and that of the grain as computed by a comparison of Periods II and III are represented by full lines and the other results by broken lines.

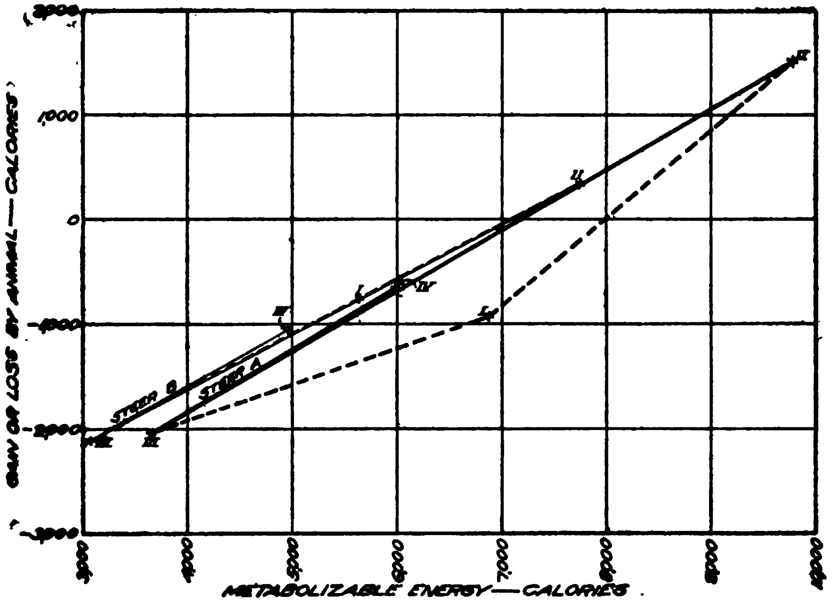

FIG. 7.—Availability of metabolizable energy, experiments of 1905.

### AVAILABILITY ABOVE AND BELOW MAINTENANCE.

A computation of the availability by a comparison of Periods II and III assumes that the same percentage is available above and below the maintenance requirement. In previous publications[1] we have expressed the belief, based in part upon experimental results and in part upon theoretical considerations, that this is not the case, but that the proportion of metabolizable energy capable of being stored up as gain after the maintenance requirement is satisfied is materially less than that available below the maintenance requirement-

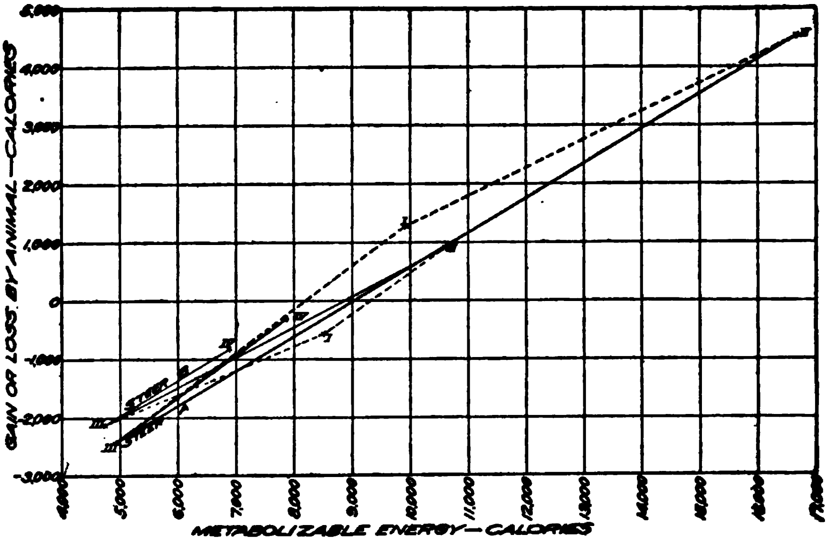

FIG. 8.—Availability of metabolizable energy, experiments of 1906.

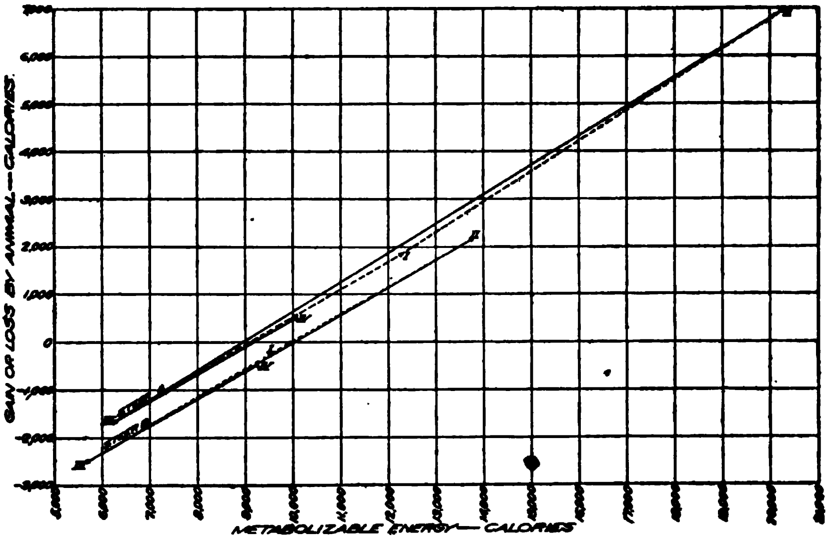

FIG. 9.—Availability of metabolizable energy, experiments of 1907.

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[1] Bureau of Animal Industry Bul. 51, p. 64, and Bul. 74, pp. 42-44; "Principles of Animal Nutrition," pp. 444-446.

ment to diminish the loss of energy from the body. The results of the present series of experiments fail to support that view. The experiments upon hay alone were all upon quantities below the maintenance requirement, with the exception of steer A in Period IV of the experiments of 1907, and even in this case the ration was but slightly in excess of maintenance. In the case of the mixed rations of hay and grain, however, Period I, in which a light grain ration was added to the hay of the basal ration of Period III, was intended to be approximately a maintenance ration, while in Period II the amount of grain was increased so as to cause a material gain by the animals. As a matter of fact, the ration of Period I was less than the maintenance requirement of steer B in every case, while with steer A on the contrary it was somewhat above the maintenance requirement except in the experiments of 1905. If, now, it be true that the percentage availability is less above the maintenance requirement than below, then the availability computed from a comparison of Periods I and II should be less than that computed from a comparison of Periods I and III. In the experiments of 1907, in which, as noted, the results seem most concordant, the availability computed from Periods I and II is in one case greater than in the other case less than that computed from Periods I and III, the difference being relatively small in both cases. Both the figures of Table 16 and the graphic representation of the results appear to indicate clearly that in this series the percentage of the metabolizable energy of the grain which was available was substantially independent of whether the amounts consumed were above or below the maintenance requirement. In the other two years, in which the results are less satisfactory, the availability computed above the maintenance requirement, i. e., from Periods I and II, is in two cases greater and in two cases less than that computed below, but the differences are decidedly greater. In consideration of the greater weight attaching to the concordant results of the experiments of 1907, we are inclined to conclude that the percentage of the metabolizable energy of the grain available was substantially the same above and below the maintenance requirement and that the discrepancies in the earlier experiments are perhaps due to errors affecting particularly the results of Period I.

A reconsideration of the experimental evidence upon which we based our earlier view points to the same conclusion. In the experiments on timothy hay, reported in the first of the publications cited, only one period showed a gain of energy by the animal and this amounted to only 266 calories. Attention was called to this fact in the discussion of the results and it was specifically stated that much stress should not be laid upon the results of this period. In the experiments with corn meal in 1903, reported in the second of the publications cited, however, a gain of 3,525 calories was obtained in the period of heavy feeding, and from this we computed a percentage utilization of 53.28 as compared with a percentage availability below maintenance of 77.81. In this computation, however, we failed to take due account of the fact that in these experiments the proportion of time spent standing was notably greater in the period of heavy feeding (Period IV) than in the others, a fact which would tend to reduce the gain by the animal. In connection with the detailed description of the respiration calorimeter experiments in Part II of this bulletin, we have included a recalculation of the results, making the corrections for standing and lying, for live weight, and for differences in the amount of hay consumed in percisely the same manner as in the three series of experiments under discussion. In the experiments of 1903 the minimum ration of hay was given in Period II, the light grain ration (much below maintenance) in Period III and the heavy grain ration in Period IV. The final results for availability are as follows:

TABLE 17.—*Recalculated availability of metabolizable energy, 1903.*

| | Per cent. |
|---|---|
| Red clover hay: | |
| Periods I-II | 44.04 |
| Corn meal: | |
| Light ration, Periods III-II | 66.22 |
| Heavy ration, Periods IV-II | 69.12 |
| Heavy ration, Periods IV-III | 70.83 |

These figures, as well as the graphic representation of the results on figure 10, like those of the three series of 1905-1907, fail to give any evidence of a decreased availability above the point of maintenance as compared with that below.

### SUMMARY OF AVAILABILITY.

If, then, we are justified in concluding that the percentage availability is the same above and below maintenance, it would seem that the most satisfactory measure of the availability of the energy of the grain in the experiments under discussion will be obtained by comparing the results of Period II, in which the maximum amount of grain was fed, with those of Period III upon hay alone, regarding the latter as the basal ration, since this comparison affords the widest range in the amount of grain consumed, thus presumably reducing the relative error. Upon this basis, we obtain the following comparison of the results upon the two animals in the three series of experiments:

TABLE 18.—*Summary of availability of metabolizable energy.*

| | Steer A. | Steer B. |
|---|---|---|
| *Timothy hay.* | | |
| Experiments of 1905 | 60.51 | 55.21 |
| Experiments of 1906 | 71.49 | 60.86 |
| Experiments of 1907 | 57.05 | 56.50 |
| *Wheat bran.* | | |
| Experiments of 1905 | 58.74 | 51.98 |
| *Mixed grain.* | | |
| Experiments of 1906 | 58.89 | 51.51 |
| Experiments of 1907 | 61.55 | 57.71 |

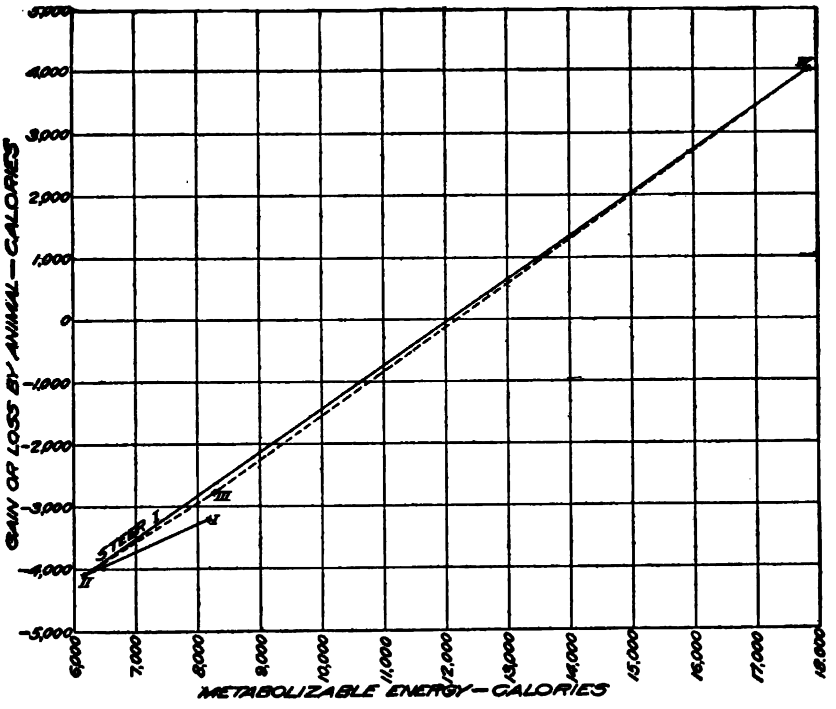

FIG. 10.—Availability of metabolizable energy, experiments of 1903.

### INFLUENCE OF AGE OF ANIMAL ON AVAILABILITY.

One of the objects of the investigation was to compare the percentage availability in the same animal at different ages. This purpose was largely frustrated, however, by the impossibility of obtaining hay of identical quality in the three years and likewise by the necessity of changing to a mixed-grain ration in order to secure the consumption of an adequate amount.

As noted in the discussion of the results upon digestibility, the hay used in 1905 was of decidedly poorer quality than that of the other two years, being low in protein and high in crude fiber. The latter fact, as has been well established by Kellner's investigations, tends to increase the expenditure of energy in digestion and assimilation, or, in other words, to diminish the percentage availability of the energy. Notwithstanding this, however, the availability found for the poorer hay, as compared with that observed with the better quality in 1907, was but 1.29 less in the case of steer B, and 3.46 greater with steer A. These results might be taken to indicate a relatively greater availability by the younger animal were it not for the rather unsatisfactory character of the experiments of 1905. The results on the hay in 1906 seem abnormally high, being greater for each animal than those for the grain.

In the case of the grain a comparison of the results in 1906 and 1907 upon practically identical mixtures shows a higher percentage availability in the case of the older animal, especially with steer B, although here, too, the differences are rather small. On the whole, while the results as regards the influence of age are indecisive, they afford little support to the belief in a greater ability of young animals to utilize the metabolizable energy of their feed.

### INFLUENCE OF INDIVIDUALITY UPON AVAILABILITY.

It is not easy to form a judgment as to the probable error involved in the results of complicated experiments like the foregoing, and the significance of small differences may readily be exaggerated. In the experiments of 1907, which, as already pointed out, are the most satisfactory of the three series, there is a difference in the percentage availability of 3.84 in the case of the grain and 0.55 in that of the hay in favor of steer A as compared with steer B. These differences are small, and in the case of the hay especially seem practically negligible. They appear to gain somewhat in significance, however, from the fact that the differences observed in the earlier, even though less satisfactory series, are not only greater but also are uniformly in the same direction. Even including the less satisfactory comparisons contained in Table 16, this fact is true in 9 cases out of 12. Taking the results as a whole, therefore, they seem to indicate a small but distinct superiority of steer A over steer B as regards the availability of the metabolizable energy of the feed. This difference appears to be more marked in the earlier years, while as the animals matured steer B nearly or quite overtook steer A in this respect, so that it seems questionable whether the differences in the third year's experiments are of much significance.

As regards the explanation of such a difference, only speculations can be presented. It is not easy to conceive how any metabolic process or set of processes, such, for example, as are involved in the production of fat from carbohydrates, can be conducted more efficiently in one individual than in another. It would seem that if such a difference between individuals exists as is indicated by the foregoing results we must seek for its explanation in differences in the character of the body substance gained or katabolized. Upon this point, of course, respiration-calorimeter experiments afford but meager information. They show the total gain or loss of ash, nitrogenous matter, and fat (and glycogen), but reveal nothing as to the part of the body where they are deposited or katabolized, nor as to the exact nature of the material involved. It may not be without significance in this connection that, as shown on previous pages, the growth of steer A was more largely in body girth, while steer B increased relatively more rapidly in length and height, or that, as will appear later, steer A showed a tendency to fatten, while steer B inclined to gain relatively more nitrogenous material. In other words, the difference in availability may conceivably be related to the apparent difference in the nature of the gains or losses.

## THE ENERGY REQUIREMENT FOR MAINTENANCE.

From the results of the two periods on hay alone in each year it is easy to compute, on the one hand, the amount by which it would have been necessary to increase the supply of metabolizable energy to prevent any loss of potential energy from the body, or, on the other hand, to calculate the amount of potential energy which would have been lost by the animal had the ration been reduced to zero.

Thus in the case of steer A in the experiments of 1907, for example, the metabolizable energy of the hay consumed daily in Period III was 6,234.5 calories, and on this ration the body lost daily 1,679.4 calories, while a comparison with Period IV (compare p. 51) shows an availability of the metabolizable energy of 57.05 per cent. Evidently, then, to prevent the loss from the body of 1,679.4 calories it would have been necessary to add to the daily ration sufficient hay to supply $1,679.4 \div 0.5705 = 2,943.7$ calories of metabolizable energy, making the total metabolizable energy of the daily ration $2,943.7 + 6,234.5 = 9,178.2$ calories.

If, on the other hand, the ration had been reduced to zero, the loss of energy per day by the animal would have been increased by $6,234.5 \times 0.5705 = 3,556.8$ calories and the total loss would have been $1,679.4 + 3,556.8 = 5,236.2$ calories.

A precisely similar computation may, of course, be made from the data of Period IV.

In figure 11, let the points A and B represent the results of Periods III and IV, plotted in the same manner as in figure 9, the metabolizable energy in the two periods being represented, respectively, by OE and OF and the gain or loss by the animal by EA and FB, while the line AB, intersecting the horizontal axis at C, represents the percentage availability. It is plain, then, that OC represents the amount of metabolizable energy required to reduce the loss from the body to zero, that is, for maintenance, while OD evidently represents the body loss that would have occurred if the supply of metabolizable energy had been reduced to zero. That is, OD represents the computed fasting katabolism,[1] or the amount of energy actually required for the necessary internal work of the body, while the value of OC shows the amount of metabolizable energy having this particular percentage of availability, viz, 57.05, which would have been required to reach equilibrium. In other words, the maintenance *ration*, expressed in terms of metabolizable energy, is variable depending upon the percentage availability of the energy, while the maintenance *requirement* expressed in terms of the computed fasting katabolism is constant for the same animal under the same external conditions. Any ration therefore which will supply available energy equal to OD will be a maintenance ration. Thus, if the metabolizable energy of a ration had an availability of 65 per cent, represented by the line DG, the maintenance requirement in terms of available energy would still be represented by OD, but the maintenance ration expressed in terms of metabolizable energy would equal not OC but OG. Plainly it is preferable, therefore, to express the maintenance requirement as a constant in terms of available energy.

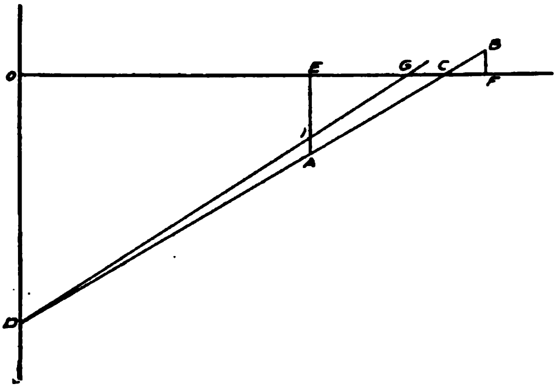

FIG. 11.—The maintenance requirement.

The computation of the maintenance requirements of the two animals in these experiments suffers from the more or less unsatisfactory nature of the results obtained with regard to the availability of the metabolizable energy of the hay in the first two years. In the experiments of 1906 in particular, the percentage availability of the energy of the hay appears to be too high. In the case of steer A especially the results are not only larger than those obtained in 1905 and in 1907, but are higher than the figures found for the availability of the mixed grain, a result which seems unlikely. The hay used was similar in composition and digestibility to that used in 1907 and the computation of the maintenance requirement has been made by assuming the availability of its energy to have been the same as that found for the corresponding animal in the year 1907.

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[1] On the assumption, of course, that the experiment is made at or above the critical external temperature for the animal.

Computed on this assumption and in the manner shown in the foregoing example, the maintenance requirements of the two animals in the three series of experiments were as shown in Table 19. For the sake of ready comparison, the results have also been recalculated to a uniform weight of 500 kilograms in proportion to the two-thirds power of the live weight.

TABLE 19.—*Computed maintenance requirements in terms of available energy.*

| | Steer A. | Steer B. |
|---|---|---|
| Per day and head: | *Calories.* | *Calories.* |
| Experiments of 1905 | 4,396 | 3,946 |
| Experiments of 1906 | 5,228 | 4,801 |
| Experiments of 1907 | 5,236 | 5,821 |
| Per day and 500 kilos live weight: | | |
| Experiments of 1905 | 6,649 | 7,532 |
| Experiments of 1906 | 6,077 | 6,806 |
| Experiments of 1907 | 5,186 | 6,931 |

The experiments of 1907, the results of which are the most satisfactory, show a marked difference between the two animals as regards the maintenance requirement, that of steer B being 33.7 per cent higher than that of steer A. The results obtained in 1905 and 1906 naturally have less weight, but nevertheless they show a difference in the same general direction. On the average of the three years' experiments the available energy required for maintenance per 500 kilograms live weight was: Steer A, 5,971 calories; steer B, 7,090 calories. Even omitting the relatively low result for steer A in 1907, the average for steer A is materially lower than that for steer B.

The correction of the results to a uniform time of 12 hours standing may be assumed to have approximately eliminated any difference in the maintenance requirement due to the influence of standing or lying. Steer B possessed the active, nervous temperament of the dairy type, while steer A showed the quiet, almost phlegmatic disposition of the typical beef animal. The figures appear to show that this difference in temperament, aside from any effect which it had upon the amount of time spent standing or lying, very materially affected the maintenance requirement. If such differences prove to be characteristic of the two types of animals, they will go far toward explaining the economic superiority of the beef type.

With the exception of steer B in 1907, the relative maintenance requirement shows a marked decrease from year to year. We may conjecture that this is due to lessened muscular activity with advancing maturity.

## ENERGY VALUES OF FEEDING STUFFS.

In order to have a basis for estimating the available energy of the rations in periods not covered by the calorimeter experiments, it appears desirable to compute from the foregoing results the energy values of the feeds used, while it will be of interest also to compare the experimental results with those obtained by applying Kellner's factors to the digestible nutrients as computed from the results of the digestion experiments.

### TIMOTHY HAY.

The total chemical energy of the hay in each of the three years is recorded in Table 4, page 26, while the average percentage of it which was metabolizable is shown in Table 12, page 36, the difference between the two animals in this respect being insignificant. The percentage availability of the metabolizable energy, as shown in Table 18, page 51, and in the subsequent discussion, appears to have been slightly greater by steer A than by steer B, but the differences seem too small to be of any importance in such a general comparison of rations as is attempted on subsequent pages. Accordingly, the average percentage availability by the two animals is made the basis of the computation. Furthermore, as noted in the discussion of the percentage availability, the results upon hay in the year 1906 are questionable. They have therefore been rejected in the following computation and the average result with the two animals in the experiments of 1907 has been used, as was the case in the computation of the maintenance requirement on page 55. The content of available energy therefore has been calculated from the metabolizable energy by the use of the following percentages of availability:

| | Per cent. |
|---|---|
| Experiments of 1905 | 57.86 |
| Experiments of 1906 | 56.78 |
| Experiments of 1907 | |

Computed in this way, the energy values of the hay are:

TABLE 20.—*Energy values per gram of dry matter of timothy hay.*

| | Experiments of— | | |
|---|---|---|---|
| | 1905 | 1906 | 1907 |
| | *Calories.* | *Calories.* | *Calories.* |
| Digested energy | 2.2243 | 2.3347 | 2.6266 |
| Metabolizable energy | 1.7782 | 1.8610 | 2.0567 |
| Available energy | 1.0288 | 1.0567 | 1.1678 |

### WHEAT BRAN.

But one series of experiments, viz, that of 1905, was made upon wheat bran alone. As was the case with the hay, the percentage of the total energy metabolizable, as shown in Table 13, page 37, differed but slightly as between the two animals. The percentage availability of the metabolizable energy was 6.76 per cent greater with steer A than with steer B, but it may be questioned whether this difference is significant. The energy values of the wheat bran are as follows:

TABLE 21.—*Energy values per gram of dry matter of wheat bran.*

| | Calories. |
|---|---|
| Digested energy | 3.0942 |
| Metabolizable energy | 2.5149 |
| Available energy: | |
| Steer A | 1.4773 |
| Steer B | 1.3072 |
| Average | 1.3923 |

### MIXED GRAIN.

The mixed grain in the experiments of 1906 and 1907 consisted, as previously stated, of 1 part by weight of wheat bran, 3 of corn meal, and 3 of old-process linseed meal. The energy values of the separate ingredients of this mixture were not determined, but only that of the mixture as a whole. Using the averages of the results obtained with the two animals for the percentage of the total energy digestible, metabolizable, and available, we have the following results:

TABLE 22.—*Energy values per gram of dry matter of mixed grain.*

| | Experiments of— | | Average of the 2 years. |
|---|---|---|---|
| | 1906 | 1907 | |
| | *Calories.* | *Calories.* | *Calories.* |
| Digested energy | 3.8508 | 3.7032 | 3.7770 |
| Metabolizable energy | 3.1457 | 2.9758 | 3.0608 |
| Available energy: | | | |
| Steer A | 1.8525 | 1.8316 | 1.8421 |
| Steer B | 1.6204 | 1.7173 | 1.6689 |
| Average | 1.7365 | 1.7745 | 1.7555 |

### COMPUTED ENERGY VALUES.

Applying to the average composition of the feeds used in the three experiments as shown in Tables 4 and 7, pages 26 and 31, the average of the coefficients for the two steers as recorded in Tables 5 and 8, pages 27 and 32, we obtain the figures of Table 23 for the so-called digestible nutrients computed in the customary way. The corn meal used in the investigations of 1903, reported in Bulletin No. 74 of this bureau, the availability of whose energy is recalculated on page 50, has also been included in the table.

TABLE 23.—*Digestible nutrients in dry matter of feeding stuffs.*

| | Timothy hay. | | | Wheat bran. | Mixed grain. | | | Corn meal. |
|---|---|---|---|---|---|---|---|---|
| | 1905 | 1906 | 1907 | 1905. | 1906 | 1907 | Average. | 1903. |
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Protein | 0.73 | 2.35 | 3.02 | 11.18 | 12.61 | 13.80 | 13.20 | 6.58 |
| Nonprotein | .39 | .83 | .24 | .49 | 3.43 | 2.22 | 2.83 | .48 |
| Carbohydrates [1] | 49.89 | 47.89 | 55.33 | 47.95 | 57.05 | 56.50 | 56.78 | 80.39 |
| Ether extract | .96 | 1.25 | 1.04 | 3.31 | 6.03 | 4.77 | 5.40 | 4.05 |
| Total | 51.97 | 52.32 | 59.63 | 62.93 | 79.12 | 77.29 | 78.21 | 91.50 |

[1] Sum of digestible crude fiber and digestible nitrogen-free extract.

From the results contained in Table 23, together with the percentage of total crude fiber contained in the several feeds, we may compute their production values according to Kellner by the use of the factors which he has worked out. These are:[1]

*Production values per gram.*

| | Calories. |
|---|---|
| Digestible protein | 2.24 |
| Digestible starch and crude fiber | 2.36 |
| Digestible cane sugar | 1.79 |
| Digestible ether extract: | |
| In coarse fodders | 4.50 |
| In cereals and legumes and their by-products | 5.00 |
| In feeds containing over 5 per cent of fat | 5.70 |

The factor for the protein is applied only to the true protein, the nonprotein being ignored in the computation. From the total energy thus computed there must be deducted in the case of hay, straw, and similar coarse fodders 1.36 calories and in the case of chaff and like materials 0.66 calories for each gram of total crude fiber present. In the case of concentrated feeds the total is multiplied by a percentage expressing the relative energy value of the digestible matter as compared with digestible starch or other pure nutrients, these percentages (Wertigkeit) being based on the results of experiments by Kellner which have not yet been published in full. As applied, for example, to the hay of the experiments of 1907, the computation would be as follows:

*In 1 gram dry matter.*

| | Calories. |
|---|---|
| Digestible protein | 0.0302×2.24=0.0676 |
| Digestible carbohydrates | .5533×2.36=1.3058 |
| Digestible ether extract | .0104×4.50= .0468 |
| | 1.4202 |
| Total crude fiber | .3115×1.36= .4237 |
| Production value | .9965 |

For the grains used in these experiments Kellner gives the following percentages by which the production values as obtained by computation from the digestible protein, carbohydrates, and fat are to be multiplied: Wheat bran, 77 per cent; corn meal, 100 per cent; linseed cake, 97 per cent. For a mixture of these in the proportion used in these experiments the average value would be 95 per cent. Kellner's production values attempt to show the amount of energy which will be stored up in the body of an animal as gain of flesh and fat when a unit of the feed is added to a ration already fully sufficient for maintenance.

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[1] "Die Ernährung der Landwirtschaftl. Nutztiere," 5th ed., pp. 149 and 159.

TABLE 24.—*Comparison of observed and computed energy values per gram dry matter.*

| Feed. | Observed available energy. | Computed production values. | Computed ÷observed. |
|---|---|---|---|
| | *Calories.* | *Calories.* | *Per cent.* |
| Timothy hay: | | | |
| Experiments of 1905 | 1.0288 | 0.7183 | 69.82 |
| Experiments of 1906 | 1.0567 | .7900 | 74.76 |
| Experiments of 1907 | 1.1678 | .9965 | 85.33 |
| Average of American timothy hay [1] | | .8525 | |
| Wheat bran: | | | |
| Experiments of 1905— | | | |
| Steer A | 1.4773 | | |
| Steer B | 1.3072 | | |
| Average | 1.3923 | 1.1916 | 85.58 |
| Mixed grains: | | | |
| Experiments of 1906— | | | |
| Steer A | 1.8525 | | |
| Steer B | 1.6204 | | |
| Average | 1.7365 | 1.8314 | 105.47 |
| Experiments of 1907— | | | |
| Steer A | 1.8316 | | |
| Steer B | 1.7173 | | |
| Average | 1.7745 | 1.7870 | 100.70 |
| Average of both years— | | | |
| Steer A | 1.8421 | | |
| Steer B | 1.6689 | | |
| Average | 1.7555 | 1.8092 | 103.07 |
| Corn meal: | | | |
| Experiments of 1903 [2] | 2.3460 | 2.2471 | 95.78 |

[1] U. S. Department of Agriculture, Farmers' Bulletin 346, p. 15.
[2] Using corrected availability for Periods IV-II, Table 17.

As was shown on pages 47–50, our results indicate that in the case of the grain the availability was the same above and below the point of maintenance and the very good agreement between the observed and computed energy values shown by the foregoing table in the case of the mixed grain, especially in the experiments of 1907, appears entirely in harmony with this conclusion.

On the other hand, the results upon the hay show a marked discrepancy, the computed energy value ranging from 70 to 85 per cent of the observed. The observed results on the hay, however, represent substantially the availability of its energy below the point of maintenance and the comparison perhaps indicates that on the light hay rations used in these experiments the availability of the energy is greater than when, as in Kellner's experiments, the hay is added to a liberal basal ration and when, therefore, the volume of the contents of the alimentary canal is considerably greater. In other words, it seems not impossible that, as Kellner has suggested,[1] there may be an optimum volume of the contents of the digestive tract below which the expenditure of energy in the mechanical work of digestion is not materially affected by the amount of food consumed. It is hoped that subsequent experiments now in process of computation may throw some light upon this point.

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[1] "Die Ernährung der Landwirtschaftl. Nutztiere," 5th ed., p. 164.

It will be noted that the results obtained upon the bran in 1905 show almost as great a discrepancy as compared with the computed as do those obtained upon the hay. No obvious explanation of this difference presents itself, although it may be noted that all the rations in this series of experiments were comparatively light.

### THE INTERMEDIATE FEEDING PERIODS.

The prime object of the respiration-calorimeter experiments was to compare the digestibility of the feeding stuffs and the percentage of their energy metabolizable, as well as the availability of the latter, by the two animals and in the successive seasons. For these purposes, especially the latter, it was necessary in some periods to give rations less in amount than the maintenance requirement. As already stated, there were four respiration-calorimeter periods each winter, covering in all, including preliminary and transition feeding, about three months. During three of these periods the animals were on rations either below or but little above the maintenance requirement. The ration of the remaining period was fairly comparable in kind and amount with the feeding during the remainder of the year, but this period was interpolated between two periods of low feeding and was too short (three to four weeks) to give the determination of the gain of live weight any material value. During about three months of each year, therefore, the live weight of the animals, especially of steer B, was either at a standstill or showed only a very moderate gain. During the remaining nine months of the year, designated as "intermediate feeding periods," the aim was to supply a ration which should be sufficient to produce normal growth but not such as to fatten the animals.

### RATIONS CONSUMED.

At the outset of the investigation and up to April 12, 1906, inclusive, with the exception, as stated, of the respiration-calorimeter periods of 1905, the grain consisted of the same mixture which was employed in the respiration-calorimeter experiments of the second and third years, viz:

| | Parts by weight. |
|---|---|
| Clear corn meal | 3 |
| Linseed meal | 3 |
| Wheat bran | 1 |

From that time until July 31, 1906, inclusive, the grain mixture consisted of—

| | Parts by weight. |
|---|---|
| Corn and cob meal | 3 |
| Linseed meal | 1 |
| Wheat bran | 1 |

From August 1 to December 15, 1906, the use of linseed meal was discontinued, the grain ration consisting of—

| | Parts by weight. |
|---|---|
| Corn and cob meal | 2 |
| Wheat bran | 1 |

During the remainder of the investigation the animals were either upon the rations of the respiration calorimeter periods or those preliminary to them.

The coarse feed for the intermediate periods above referred to consisted during the winter of mixed clover and timothy hay, the timothy predominating. During the summer and fall of each year, viz, from July 16 to October 5, 1905, and from July 7 to November 30, 1906, the hay was replaced by the green soiling crops or ensilage which were being fed to the dairy herd.

Each animal received, per 1,000 pounds live weight, 7 pounds of the grain mixture, the amount of feed being based upon the average of three weighings of the animal at the end of each month. The amount of coarse fodder consumed was regulated by the appetite of the animal.

### FEEDING RECORD.

The complete feeding records of the two animals, exclusive of the calorimeter periods, are contained in Table III of the appendix. The following summary, Table 25, shows the totals and averages for the periods into which the feeding naturally divides itself according to the kinds of feed consumed, and corresponding also to the grouping of the live weight results in Table 52, page 78. In those periods in which green soiling crops were fed, the air-dry weights consumed, as computed from the percentages given in Table III of the appendix, are recorded as being most nearly comparable with the gross weights of the other feeding stuffs. The percentage of air-dry matter in the soiling crops was determined, in connection with the observations on the dairy herd, upon a composite daily sample representing the entire period during which the given feed was used.

TABLE 25.—*Intermediate feeding periods—Feeding record per head.*

| Date of feeding period. | Number of days. | Mixed hay. | Timothy hay. | Soiling crops, air-dry. | Wheat bran. | Corn meal. | Corn and cob meal. | Linseed meal. | Total air-dry feed. | Average air-dry feed per day. |
|---|---|---|---|---|---|---|---|---|---|---|
| *Steer A.* | | *Kilos.* | *Kilos.* | *Kilos.* | *Kilos.* | *Kilos.* | *Kilos.* | *Kilos.* | *Kilos.* | *Kilos.* |
| Oct. 1 to Dec. 10, 1904 | 71 | 252.2 | ........ | ........ | 17.73 | 53.18 | ........ | 53.18 | 376.29 | 5.30 |
| Apr. 2 to July 15, 1905 | 105 | 258.8 | 72.00 | ........ | 36.74 | 110.22 | ........ | 110.22 | 587.98 | 5.60 |
| July 16 to Oct. 5, 1905 | 82 | 5.2 | ........ | 205.26 | 29.29 | 87.86 | ........ | 87.86 | 415.47 | 5.07 |
| Oct. 6 to Dec. 3, 1905 | 59 | 131.7 | 79.83 | ........ | 20.86 | 62.58 | ........ | 62.58 | 357.55 | 6.06 |
| Apr. 8 to July 6, 1906 | 90 | 478.6 | ........ | ........ | 53.09 | 6.00 | 153.26 | 57.09 | 748.04 | 8.31 |
| July 7 to 31, 1906 | 25 | ........ | ........ | 47.40 | 12.00 | ........ | 36.00 | 12.00 | 107.40 | 4.30 |
| Aug. 1 to Oct. 25, 1906 | 87 | 2.0 | ........ | 167.65 | 72.50 | ........ | 145.00 | ........ | 387.15 | 4.45 |
| Oct. 26 to Dec. 15, 1906 | 50 | 190.6 | ........ | 55.94 | 34.66 | ........ | 69.32 | ........ | 350.52 | 7.01 |
| *Steer B.* | | | | | | | | | | |
| Oct. 1 to Dec. 10, 1904 | 71 | 252.2 | ........ | ........ | 12.49 | 37.47 | ........ | 37.47 | 339.63 | 4.78 |
| May 7 to July 15, 1905 | 70 | 234.7 | ........ | ........ | 19.99 | 59.97 | ........ | 59.97 | 374.63 | 5.35 |
| July 16 to Oct. 5, 1905 | 82 | 4.4 | ........ | 204.91 | 23.42 | 70.27 | ........ | 70.27 | 373.27 | 4.55 |
| Oct. 6 to Dec. 3, 1905 | 59 | 133.6 | 70.88 | ........ | 16.34 | 49.02 | ........ | 49.02 | 318.86 | 5.40 |
| Apr. 15 to July 6, 1906 | 83 | 386.3 | ........ | ........ | 36.35 | ........ | 109.04 | 36.35 | 568.04 | 6.84 |
| July 7 to 31, 1906 | 25 | ........ | ........ | 47.00 | 11.16 | ........ | 33.48 | 11.16 | 102.80 | 4.11 |
| Aug. 1 to Oct. 25, 1906 | 87 | ........ | ........ | 185.30 | 68.28 | ........ | 136.56 | ........ | 390.14 | 4.48 |
| Oct. 26 to Dec. 15, 1906 | 50 | 160.6 | ........ | 55.94 | 33.47 | ........ | 66.94 | ........ | 316.95 | 6.34 |

Owing to his smaller size, steer B consumed somewhat less air-dry feed than did steer A. In proportion to his size, however, he consumed notably more. This is true in every case when the comparison is made per thousand pounds of live weight. If the comparison is made on the basis of the two-thirds power of the live weight (that is, approximately in proportion to the surface), only one exception to the rule occurs.

## COMPOSITION OF FEEDING STUFFS.

Tables 26 and 27 contain the results of the analyses which were made of the feeding stuffs used in the intermediate feeding periods and in the digestion and metabolism experiments which were included in those periods. The results are grouped under the same dates shown in Table 25, the date at which the samples were taken being also shown. Details regarding the exact period covered by each sample, as well as other particulars, will be found in the notes appended to the tables. In a considerable number of instances only the loss of moisture on air drying and the nitrogen in the air-dry material were determined. To facilitate comparison of the results, the partial dryings have therefore been tabulated. In a few instances, due to an oversight, the moisture in the air-dry feeding stuff was not determined, and it has been necessary to assume a figure for it. These assumed percentages, as well as all the percentages affected by the assumption, are distinguished by being inclosed in brackets.

TABLE 26.—*Composition of feeding stuffs in intermediate feeding periods.*

| Feed and period. | Date of sampling. | Air-dry matter in fresh substance. | In air-dry matter. |  | Dry matter in fresh substance. | In dry matter. |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Dry matter. | Nitrogen. |  | Ash. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Energy, calories per gram. |
| *Mixed hay.* |  | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* |  |
| Oct. 1 to Dec. 10, 1904 | Nov. 26, 1904 | ...... | ...... | ...... | ...... | 8.09 | 12.88 |  | 28.25 | 50.78 |  | 2.060 | ...... |
|  | ....do | ...... | ...... | ...... | ...... | 7.92 | 13.20 |  | 28.30 | 50.58 |  | 2.112 | ...... |
|  | Nov. 28, 1904[1] | 91.80 | [89.79] | 1.873 | [82.42] | ...... | ...... | ...... | ...... | ...... | ...... | [2.086] | ...... |
| Apr. 2 to July 15, 1905 | June 28, 1905[1] | 92.50 | 90.99 | 2.020 | 84.25 | 6.69 | 12.25 | 1.22 | 30.39 | 46.09 | 3.36 | 2.220 | 4.5940 |
| Oct. 6 to Dec. 3, 1905 | Oct. 4, 1905 | 99.23(?) |  | 1.210 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
|  | Oct. 31, 1905 | 90.70 | 95.22 | 1.640 | 86.36 | 6.32 | 9.06 | 1.28 | 29.88 | 51.08 | 2.38 | 1.722 | ...... |
|  | Nov. 6, 1905[1] | 91.97 | 95.28 | 1.490 | 87.63 | 5.98 | 8.26 | 2.14 | 31.70 | 48.83 | 3.09 | 1.564 | 4.5005 |
| Apr. 8 to July 6, 1906 | Oct. 31, 1905[2] | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
|  | June 18, 1906[1] | 98.04 | 88.44 | 1.803 | 86.71 | 7.12 | 11.14 | 1.20 | 30.04 | 47.91 | 2.59 | 2.039 | 4.4531 |
| Oct. 26 to Dec. 15, 1906 | June 18, 1906[2] | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| *Wheat bran.* |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Oct. 1 to Dec. 10, 1904 | Oct. 1, 1904 | 92.10 | [94.42] | 2.475 | [86.96] | [8.81] | [14.94] |  | [10.55] | [65.70] |  | [2.621] | ...... |
|  | Nov. 29, 1904[1] | 91.50 | [94.42] | 2.460 | [86.39] | ...... | ...... | ...... | ...... | ...... | ...... | [2.606] | ...... |
| Apr. 2 to July 15, 1905 | June 28, 1905[1] | 98.00 | 90.51 | 2.397 | 88.70 | 7.02 | 12.54 | 2.12 | 10.13 | 63.02 | 5.17 | 2.648 | 4.5841 |
| July 16 to Oct. 5, 1905 | Aug. 2, 1905 | 97.26 | ...... | 2.515 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| Oct. 6 to Dec. 3, 1905 | Oct. 13, 1905 | Lost. | ...... | 2.567 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
|  | Nov. 4, 1905[1] | 91.84 | 95.45 | 2.705 | 87.66 | 7.08 | 13.38 | 2.32 | 9.70 | 63.58 | 3.94 | 2.840 | 4.5058 |
|  | Dec. 4, 1905 | 92.00 | ...... | 2.985 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| Apr. 8 to July 6, 1906 | Oct. 13, 1905[3]<br>Dec. 4, 1905 | 92.00 | 90.16 | 2.759 | 82.96 | 7.30 | 12.67 | 3.93 | 9.82 | 62.37 | 3.91 | 3.060 | ...... |
|  | Apr. 11, 1906 | 93.30 | ...... | 2.806 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
|  | June 11, 1906 | 92.60 | ...... | 2.743 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
|  | June 16, 1906[1] | 96.00 | 90.16 | 2.716 | 86.56 | 7.56 | 14.56 | 2.15 | 9.65 | 61.07 | 5.01 | 3.012 | 4.5397 |
| July 7 to 31, 1906 | June 11, 1906[2] | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| Aug. 1 to Oct. 25, 1906 | July 30, 1906 | 98.00 | ...... | 2.634 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
|  | Oct. 4, 1906 | 93.20 | ...... | 2.604 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| Oct. 26 to Dec. 15, 1906 | Oct. 4, 1906[2] | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| *Corn meal.* |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Oct. 1 to Dec. 10, 1904 | Oct. 1, 1904 | 92.80 | [90.12] | 1.450 | [83.63] | [1.52] | [9.65] |  | [1.84] | [86.99] |  | [1.609] | ...... |
|  | Nov. 29, 1904[1] | 92.50 | [90.12] | 1.413 | [83.36] | ...... | ...... | ...... | ...... | ...... | ...... | [1.568] | ...... |
| Apr. 2 to July 15, 1905 | June 28, 1905[1] | 96.80 | 89.91 | 1.337 | 87.03 | 1.48 | 8.22 | 0.61 | 2.40 | 83.69 | 3.60 | 1.487 | 4.4773 |
| July 16 to Oct. 5, 1905 | Aug. 2, 1905 | 96.33 | ...... | 1.475 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |

[1] Sample for digestion and metabolism.

[2] See above.

[3] Composite sample.

TABLE 26.—*Composition of feeding stuffs in intermediate feeding periods*—Continued.

| Feed and period | Date of sampling. | Air-dry matter in fresh substance. | In air-dry matter. | | Dry matter in fresh substance. | In dry matter. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Dry matter. | Nitrogen. | | Ash. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Energy, calories per gram. |
| *Corn meal*—Continued. | | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* |
| | Oct. 13, 1905[1] | 92.00 | ........ | 1.440 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |
| Oct. 6 to Dec. 3, 1905 | Nov. 4, 1905[2] | 91.25 | 95.38 | 1.490 | 87.03 | 1.39 | 8.99 | 0.30 | 2.27 | 84.14 | 2.91 | 1.562 | 4.4077 |
| | Dec. 4, 1905[1] | 88.83 | ........ | 1.495 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |
| | Oct. 13, 1905<br>Dec. 4, 1905[3] | ........ | 92.58 | 1.487 | ........ | 1.83 | 9.21 | 0.34 | 2.23 | 82.91 | 3.48 | 1.606 | ........ |
| Apr. 8 to July 6, 1906 | Apr. 11, 1906[5] | 93.50 | ........ | 1.375 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |
| | June 11, 1906[5] | 91.50 | ........ | 1.398 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |
| | June 16, 1906[2,5] | 93.30 | 90.37 | 1.336 | 86.13 | 1.76 | 8.54 | 0.26 | 8.41 | 77.14 | 3.89 | 1.478 | 4.5233 |
| July 7 to 31, 1906 | June 11, 1906[4] | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |
| Aug. 1 to Oct. 25, 1906 | July 30, 1906[5] | 81.00 | ........ | 1.071 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |
| | Oct. 4, 1906[5] | 94.60 | ........ | 1.258 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |
| Oct. 26 to Dec. 15, 1906 | do.[1] | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |
| *Linseed meal.* | | | | | | | | | | | | | |
| Oct. 1 to Dec. 10, 1904 | Oct. 1, 1904 | 94.40 | [94.64] | 5.235 | [89.34] | [5.78] | [30.46] | | [9.39] | [54.37] | | [5.540] | ........ |
| | Nov. 29, 1904[2] | 93.50 | [94.64] | 5.383 | [88.49] | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |
| Apr. 2 to July 15, 1905 | June 28, 1905[2] | [0] | 90.85 | 5.060 | [90.85] | 5.67 | 27.21 | 2.93 | 9.46 | 47.07 | 7.66 | 5.570 | 4.9244 |
| July 16 to Oct. 5, 1905 | Aug. 2, 1905 | 98.00 | ........ | 5.490 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |
| | Oct. 13, 1905 | 95.00 | ........ | 5.995 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |
| Oct. 6 to Dec. 3, 1905 | Nov. 4, 1905 | 95.77 | 94.52 | 5.925 | 90.52 | 4.91 | 29.87 | 3.58 | 8.00 | 52.15 | 1.49 | 6.192 | 4.7838 |
| | Dec. 4, 1905 | 94.00 | ........ | 5.885 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |
| | Oct. 13, 1905<br>Dec. 4, 1905[3] | ........ | 92.07 | 5.861 | ........ | 4.94 | 27.98 | 6.02 | 9.43 | 44.25 | 7.38 | 6.366 | ........ |
| Apr. 8 to July 6, 1906 | Apr. 11, 1906 | 97.20 | ........ | 5.391 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |
| | June 11, 1906 | 96.30 | ........ | 5.278 | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |
| | June 16, 1906[2] | 96.30 | 91.44 | 5.626 | 88.05 | 5.62 | 26.05 | 6.66 | 9.09 | 44.56 | 8.02 | 6.153 | 4.9642 |
| July 7 to 31, 1906 | June 11, 1906[4] | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |

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[1] See below.
[2] Sample for digestion and metabolism trial.
[3] Composite sample.
[4] See above.
[5] Corn and cob meal.

TABLE 27.—*Composition of green forage used in intermediate feeding periods.*

| Date. | Feedstuff. | Air-dry matter in fresh substance. | Nitrogen in air-dry substance. |
|---|---|---|---|
| 1905. | | *Per cent.* | *Per cent.* |
| July 16 to 28 | Alfalfa | 25.74 | 2.70 |
| July 29 to Aug. 8 | Soy beans | 20.75 | 2.11 |
| Aug. 9 to 14 | Cowpeas | 14.26 | 2.75 |
| Aug. 15 to 31 | Kafir corn and cowpeas | 16.57 | 1.37 |
| Sept. 1 to 5 | Alfalfa | 25.60 | 3.11 |
| Sept. 6 to 20 | Cowpeas | 15.70 | 2.88 |
| Sept. 21 to Oct. 3 | Corn fodder | 12.00 | 1.83 |
| Oct. 4 to 5 | Clover and grass | 62.50 | 2.34 |
| 1906. | | | |
| July 7 to 8 | Clover and timothy | 48.80 | 1.40 |
| July 9 to 16 | Oats and peas | 12.19 | 2.58 |
| July 17 to 20 | Alfalfa | 27.37 | 2.66 |
| July 21 to Aug. 3 | Silage (mixed grasses) | 30.20 | 2.00 |
| Aug. 4 to 21 | Corn fodder | 16.79 | ............ |
| Aug. 22 to 28 | Alfalfa | 20.71 | 2.75 |
| Aug. 29 to Sept. 2 | Cowpeas | 17.16 | 2.59 |
| Sept. 3 to 7 | Alfalfa | 28.36 | 2.55 |
| Sept. 8 to 21 | Kafir corn and cowpeas | 13.34 | 1.84 |
| Sept. 22 to 30 | Corn fodder | No sample. | No sample. |
| Oct. 1 to 4 | Grass | No sample. | No sample. |
| Oct. 5 to 9 | Alfalfa | 20.52 | 2.67 |
| Oct. 10 to 12 | Corn fodder | No sample. | No sample. |
| Oct. 13 to 25 | Corn silage | No sample. | No sample. |

## NOTES ON COMPOSITION OF FEEDING STUFFS.

October 1 to December 10, 1904: During October and November long hay was fed. On November 26, 1904, a portion of the same hay was cut for the digestion trials of December 1 to 10 and duplicate samples were taken in which the composition of the dry matter was determined. The average of these two analyses is regarded as representing the composition of the dry matter of the hay used in the digestion trial and also of that previously fed. On November 28, when the feeds were weighed out for the digestion trial, a second sample was taken in which only the loss in air drying and the nitrogen were determined. The percentage of moisture in the air-dry matter has been computed on the assumption that the nitrogen content was the same as the average of the two previous samples.

In the samples of grain taken during this period the determination of the moisture in the air-dry material was overlooked. The percentage given in the table is estimated from that found in similar samples in these and previous experiments.

April 2 to July 15, 1905: From April 2 to 26, steer A was fed timothy hay from the stock used for the preceding respiration-calorimeter experiments. A sample of the mixed hay used during the remainder of this time was taken on June 28, 1905, when feed was weighed out for the digestion and metabolism trial, and the same is true of the sampling of the grain.

October 6 to December 3, 1905: On October 4, hay, consisting chiefly of timothy, was weighed out and used until October 30. Beginning October 31, another lot of mixed hay containing but little clover was used, a considerable quantity being cut and mixed. This hay is represented by the samples of October 31 and November 6, 1905, the latter being taken when the feed was weighed out for the digestion trial. This hay was used up to December 3.

On October 13 and November 4, 1905, samples of the grain were taken, both samples being of the same lot, the second being taken at the time when feeds were weighed out for the digestion trials. Another set of samples of the same lot was taken December 4. The samples of October 13 and December 4 were subsequently united and an analysis made of the composite sample.

April 8 to July 6, 1906: Mixed hay, represented by the sample of October 31, 1905, was fed to both steers up to May 18, 1906, inclusive. The hay subsequently fed is represented by the sample of June 6, 1906, taken when the feed was weighed out for the digestion trial. The grain fed to steer A up to April 11 is represented by the composite of the samples taken October 13, 1905, and December 4, 1905.

The samples of April 11 and June 11, 1906, represent the mixed grain fed between April 12 and June 20, 1906, while subsequent to June 20 the grain used is represented by the samples of June 16, 1906, taken when the feed was weighed out for the digestion trial.

July 7 to 31, 1906: The grain fed during this time was the same as that represented by the sample of June 11, 1906, in the previous period.

August 1 to October 25, 1906: The grain is represented by the samples of July 30 and October 4, 1906, in which air-dry matter and nitrogen only were determined. The first sample was taken from the lot fed from August 1 to October 3, and the second sample from that fed from October 4 to October 25, 1906.

October 26 to December, 1906: Hay was fed from the lot represented by the sample of June 18, 1906, in the previous period, and the grain was the same as that represented by the samples of October 4, 1906, in the previous period.

For convenience of comparison the average composition of the feeding stuffs used in the calorimeter experiments is given in Table 28.

TABLE 28.—*Composition of feeding stuffs used in calorimeter experiments.*

| Component. | Timothy hay. | | | Wheat bran. | | | Corn meal. | | Linseed meal. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1904–5[1] | 1905–6[1] | 1906–7[1] | 1904–5[1] | 1905–6[2] | 1906–7[2] | 1905–6[2] | 1906–7[2] | 1905–6[2] | 1906–7[2] |
| | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* |
| Ash | 4.87 | 5.86 | 5.01 | 7.52 | 6.92 | 7.08 | 1.52 | 1.49 | 5.76 | 5.81 |
| Protein[3] | 5.08 | 6.72 | 6.90 | 14.50 | 14.22 | 13.40 | 9.20 | 9.92 | 25.65 | 27.48 |
| Nonprotein[3] | .39 | .83 | .24 | .49 | 2.62 | 3.10 | .63 | .84 | 6.50 | 3.80 |
| Crude fiber | 38.14 | 33.02 | 31.15 | 11.49 | 9.60 | 10.23 | 2.13 | 2.14 | 8.88 | 8.83 |
| Nitrogen-free extract | 49.51 | 51.01 | 54.55 | 61.88 | 61.90 | 62.20 | 81.26 | 82.07 | 44.85 | 47.44 |
| Ether extract | 2.01 | 2.56 | 2.15 | 4.12 | 4.74 | 3.99 | 5.26 | 4.04 | 8.36 | 6.64 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Total nitrogen | .894 | 1.251 | 1.155 | 2.648 | 3.053 | 3.012 | 1.668 | 1.725 | 6.047 | 5.807 |
| Protein nitrogen | .812 | 1.075 | 1.104 | 2.544 | 2.495 | 2.351 | 1.534 | 1.653 | 4.664 | 4.998 |

[1] Average of two "general samples."
[2] Average of samples for Periods I and II.
[3] Computed from nitrogen, using the factors stated in Part III, page 203.

## DIGESTION AND METABOLISM TRIALS.

As was stated in the introduction, four digestion and metabolism trials were made in the course of the intermediate feeding periods. The trials were made simultaneously upon the two animals, in the building containing the respiration calorimeter, upon the following dates:

TABLE 29.—*Dates of digestion and metabolism trials.*

| Year. | Preliminary period. | Excreta collected. |
|---|---|---|
| 1904 | Nov. 1 to 30 | Dec. 1 to 10. |
| 1905 | July 1 to 5 | July 6 to 15. |
| 1905 | Nov. 8 to 12 | Nov. 13 to 22. |
| 1906 | June 20 to 26 | June 27 to July 6. |

The purpose of these trials was to secure such data as was possible regarding the actual amounts of digestible matter and of metabolizable energy consumed by the steers during the several periods of the feeding and also to determine by means of the nitrogen balance the rate of growth of nitrogenous tissue in the two steers at different ages.

To secure the first of these objects, the attempt was made to have the rations in the digestion trials representative of those consumed during the intervening time. While, however, they corresponded quite closely in most cases with those of the previous two to four weeks, the variations in the hay eaten during the several periods were not inconsiderable. Consequently, it is not possible to apply the coefficients of digestibility obtained in the digestion trials directly to the average mixed rations of the corresponding periods. Nevertheless, as will appear, the results of the digestion trials may be made the basis of a fairly accurate computation of the metabolizable energy of the rations actually consumed. On the other hand, the results of these trials afford no sufficient basis for a comparison of the digestive powers of the two animals, nor of those of the same animal at different ages.

The details of these digestion and metabolism trials are recorded in Part II, pages 187 to 199. The total digestible nutrients, including the "digested" energy, in each trial were as shown in the following table:

TABLE 30.—*Digested nutrients in digestion and metabolism trials.*

| Component. | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Dec. 1 to 10, 1904. | July 6 to 15, 1905. | Nov. 13 to 22, 1905. | June 27 to July 6, 1906. | Dec. 1 to 10, 1904. | July 6 to 15, 1905. | Nov. 13 to 22, 1905. | June 27 to July 6, 1906. |
| | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Protein [1] | 216.7 | 403.0 | 406.6 | 450.4 | 260.6 | 349.0 | 363.1 | 380.9 |
| Nonprotein [1] | | 70.0 | 109.5 | 106.6 | | 61.5 | 103.1 | 81.2 |
| Crude fiber | 354.8 | 327.4 | 620.4 | 812.0 | 394.8 | 448.5 | 615.7 | 659.8 |
| Nitrogen-free extract | 1,345.6 | 1,957.4 | 2,157.1 | 2,990.0 | 1,338.4 | 1,796.2 | 1,982.7 | 2,254.8 |
| Ether extract | | 157.6 | 107.5 | 194.7 | | 141.8 | 101.7 | 141.6 |
| Total organic matter | 1,917.1 | 2,915.4 | 3,401.1 | 4,553.7 | 1,993.8 | 2,797.0 | 3,166.3 | 3,518.3 |
| Ash | 32.8 | 96.5 | 85.9 | 191.4 | 87.9 | 112.5 | 84.2 | 146.1 |
| Total dry matter | 1,949.9 | 3,011.9 | 3,487.0 | 4,745.1 | 2,081.7 | 2,909.5 | 3,250.5 | 3,664.4 |
| Total nitrogen | 45.6 | 85.1 | 89.6 | 100.1 | 45.6 | 73.4 | 79.2 | 82.1 |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Energy | .......... | 13,756.6 | 15,609.9 | 21,024.7 | .......... | 13,290.8 | 14,565.7 | 16,063.2 |
| True protein, estimating nonprotein at average of other 3 trials | 151.2 | .......... | .......... | .......... | 197.0 | .......... | .......... | .......... |

[1] Computed from nitrogen, using the factors stated in Part III, page 203.

### NITROGEN AND ENERGY BALANCES.

The nitrogen balances of the four trials are tabulated in Part II, pages 197–199. With the exception of the first trial (Dec. 1 to 10, 1904), determinations of energy were made in the feed and feces, while the energy of the urine was also determined in the first, second, and fourth trials. The results of the determinations on the feeds and feces are tabulated in Part II in connection with the analyses of those materials. Table 31 contains the results on the urine:

TABLE 31.—*Energy per gram of urine.*

| Date of experiment. | Steer A. | Steer B. |
|---|---|---|
| | *Calories per gram.* | *Calories per gram.* |
| Dec. 1 to 10, 1904 | 0.2271 | 0.2713 |
| July 6 to 15, 1905 | .1265 | .2615 |
| June 27 to July 6, 1906 | .2949 | .3010 |

The ration of November 13 to 22, 1905, did not differ widely from that of June 27 to July 6, 1906, and the energy of the urine in the former trial may be computed from that found in the latter, in proportion to the urinary nitrogen, without serious error.

Applying these figures to the weights of urine excreted, as shown in the detailed records of the experiments in Part II, upon the assumption that the energy content of the spilled urine and washings was proportional to its nitrogen content, gives the following results for the total energy of the urine:

TABLE 32.—*Total energy of daily urine.*

| Date of experiment. | Steer A. | Steer B. |
|---|---|---|
| | *Calories.* | *Calories.* |
| Dec. 1 to 10, 1904 | 1,238 | 1,412 |
| July 6 to 15, 1905 | 1,088 | 1,028 |
| Nov. 13 to 22, 1905 | [1] 1,363 | [1] 1,266 |
| June 27 to July 6, 1906 | 1,599 | 1,361 |

[1] Computed from nitrogen.

The production of methane in the digestion trials can be computed approximately from the total amount of carbohydrates digested. On the average of the respiration-calorimeter experiments of 1905 and of 1907 (compare p. 142) there were excreted 3.65 grams of carbon in the form of methane for each 100 grams of carbohydrates (nitrogen-free extract plus crude fiber) digested. Applying this factor to these experiments we can compute approximately the loss of potential energy in methane with the following results:

TABLE 33.—*Approximate daily loss of energy in methane.*

| Date of experiment. | Steer A. | Steer B. |
|---|---|---|
| | *Calories.* | *Calories.* |
| Dec. 1 to 10, 1904 | 1,106 | 1,128 |
| July 6 to 15, 1905 | 1,487 | 1,461 |
| Nov. 13 to 22, 1905 | 1,807 | 1,691 |
| June 27 to July 6, 1906 | 2,474 | 1,897 |

Combining the foregoing figures and estimates for the urine and methane with the data as to energy contained in the detailed report of the digestion trials in Part II, we may add to the nitrogen balance in each case a partial energy balance showing the approximate amount of metabolizable energy contained in the ration in each trial. The energy of the estimated hair and brushings is computed from the estimated nitrogen, the average for the three series of respiration-calorimeter experiments being 65.9 calories per gram nitrogen. The results of this computation are as follows, those figures depending upon estimates being distinguished by brackets:

TABLE 34.—*Nitrogen and partial energy balances in digestion trials.*

| | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Nitrogen. | | Energy. | | Nitrogen. | | Energy. | |
| | Income. | Outgo. | Income. | Outgo. | Income. | Outgo. | Income. | Outgo. |
| *Dec. 1 to 10, 1904.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Mixed hay | 62.5 | | [13,507] | | 62.5 | | [13,507] | |
| Wheat bran | 5.8 | | [997] | | 4.1 | | [707] | |
| Corn meal | 10.2 | | [2,818] | | 7.2 | | [2,000] | |
| Linseed meal | 37.3 | | [3,294] | | 26.5 | | [2,337] | |
| Uneaten feed | | 31.6 | | [4,682] | | 13.7 | | [1,935] |
| Feces | | 44.0 | | [7,229] | | 41.0 | | [7,384] |
| Urine | | 78.5 | | 1,238 | | 69.8 | | 1,412 |
| Hair and brushings (estimated) | | [1.4] | | [92] | | [1.2] | | [79] |
| Methane | | | | [1,106] | | | | [1,128] |
| Nitrogen balance | 39.7 | | | | 25.4 | | | |
| Metabolizable energy | | | | 6,269 | | | | 6,613 |
| Total | 155.5 | 155.5 | 20,616 | 20,616 | 125.7 | 125.7 | 18,551 | 18,551 |
| *July 6 to 15, 1905.* | | | | | | | | |
| Mixed hay | 52.3 | | 10,827 | | 52.3 | | 10,827 | |
| Wheat bran | 8.5 | | 1,464 | | 6.7 | | 1,159 | |
| Corn meal | 14.0 | | 4,208 | | 11.1 | | 3,332 | |
| Linseed meal | 53.5 | | 4,832 | | 42.3 | | 3,825 | |
| Feces | | 43.2 | | 7,574 | | 39.0 | | 5,852 |
| Urine | | 79.1 | | 1,088 | | 65.9 | | 1,028 |
| Hair and brushings (estimated) | | [1.5] | | [99] | | [1.2] | | [79] |
| Methane | | | | [1,487] | | | | [1,461] |
| Nitrogen balance | | 4.4 | | | | 6.3 | | |
| Metabolizable energy | | | | 11,083 | | | | 10,723 |
| Total | 128.2 | 128.2 | 21,331 | 21,331 | 112.4 | 112.4 | 19,143 | 19,143 |
| *Nov. 13 to 22, 1905.* | | | | | | | | |
| Mixed hay | 47.2 | | 13,566 | | 49.3 | | 14,197 | |
| Wheat bran | 9.0 | | 1,422 | | 7.1 | | 1,126 | |
| Corn meal | 14.7 | | 4,143 | | 11.6 | | 3,280 | |
| New process linseed meal | 60.5 | | 4,677 | | 47.9 | | 3,703 | |
| Feces | | 41.8 | | 8,198 | | 36.7 | | 7,740 |
| Urine | | 85.0 | | [1,363] | | 72.4 | | [1,266] |
| Hair and brushings | | [1.7] | | [112] | | [1.4] | | [92] |
| Methane | | | | [1,807] | | | | [1,691] |
| Nitrogen balance | | 2.9 | | | | 5.4 | | |
| Metabolizable energy | | | | 12,328 | | | | 11,517 |
| Total | 131.4 | 131.4 | 23,808 | 23,808 | 115.9 | 115.9 | 22,306 | 22,306 |
| *June 27 to July 6, 1906.* | | | | | | | | |
| Mixed hay | 90.5 | | 19,769 | | 72.1 | | 15,753 | |
| Wheat bran | 16.6 | | 2,495 | | 12.0 | | 1,808 | |
| Corn-and-cob meal | 24.2 | | 7,421 | | 17.6 | | 5,376 | |
| Linseed meal | 34.4 | | 2,776 | | 24.9 | | 2,011 | |
| Feces | | 65.6 | | 11,436 | | 44.5 | | 8,884 |
| Urine | | 99.7 | | 1,599 | | 77.9 | | 1,361 |
| Hair and brushings | | [1.9] | | [125] | | [1.6] | | [105] |
| Methane | | | | [2,474] | | | | [1,897] |
| Nitrogen balance | 1.5 | | | | | 2.6 | | |
| Metabolizable energy | | | | 16,827 | | | | 12,701 |
| Total | 167.2 | 167.2 | 32,461 | 32,461 | 126.6 | 126.6 | 24,948 | 24,948 |

## PROTEIN AND ENERGY CONTENT OF RATIONS FOR ENTIRE PERIODS.

As stated in the foregoing paragraphs, the rations consumed in the digestion and metabolism trials did not correspond exactly with the average of those consumed in the corresponding feeding periods. The differences do not appear to be great enough, however, in most cases to prevent the computation of a correction which shall give at least a reasonably accurate result for the protein and energy content of the rations of the entire periods.

*Protein.*—The mixed grain in the respiration-calorimeter experiments of 1906 and 1907 contained on the average 17.46 per cent of protein, which had a percentage digestibility of 75.6, making the average percentage of digestible protein in the dry matter 13.2 per cent.

Computed from the composition of the separate feeds, the mixed grain of the last digestion trial contained 13.25 per cent of protein. If we assume the same percentage digestibility for this as for that of the other three periods, viz, 75.6, this is equivalent to 10.02 per cent digestible protein in the dry matter.

The average percentage digestibility of the protein of the hay in the respiration-calorimeter experiments of 1907 was 43.7 per cent. The mixed hay of the general feeding, however, contained considerably more protein, the percentage ranging from 8.26 to 12.25 as compared with 6.90 in the timothy hay. We may presume that along with this higher proportion of protein there went a higher percentage digestibility. The experiments afford no means of computing it separately, but we have arbitrarily assumed a digestibility of 50 per cent.

Tabulating the foregoing results, we have the following:

TABLE 35.—*Digestible protein in dry matter of feeds in intermediate feeding periods.*

| Date of experiment. | Hay. | Mixed grain. |
|---|---|---|
| | *Per cent.* | *Per cent.* |
| Oct. 1 to Dec. 10, 1905 | [1] 5.79 | 13.20 |
| Apr. 2 to July 15, 1905 | 6.13 | |
| Oct. 6 to Dec. 3, 1905 | 4.13 | |
| Apr. 8 to July 16, 1906 | 5.57 | 10.02 |

[1] Assuming an average percentage of 1.46 nonprotein.

*Energy.*—For the purpose of computing corrections for the energy values, factors may be derived from the results of the respiration-calorimeter experiments.

The hay used in the general feeding was mixed clover and timothy, while that of the respiration-calorimeter experiments was timothy alone. The chemical composition of the former, however, except for the higher percentage of protein, corresponded fairly well with that of the timothy hay of the respiration-calorimeter experiments of 1907, especially as regards the percentage of crude fiber, and the energy results for the two animals in that year have been used in computing the factor for the correction.

The grains in the first three digestion and metabolism trials were substantially the same as in the respiration calorimeter experiments of 1906 and 1907 as appears from a comparison of their chemical composition as shown in Tables 26 and 28, and accordingly we may apply to the mixture the average results for steers A and B in the two years. In the fourth trial (June 27 to July 6, 1906) the proportions of the single grains were different and corn-and-cob meal was used in place of corn meal. Probably these changes would result in a somewhat lower percentage availability, but simply for use as a correction we may tentatively assume the same factors.

The factors to be used for correcting the energy results, then, as derived from Tables 18, 20, and 22, pages 51, 56, and 57, are as follows:

TABLE 36.—*Estimated energy values of feeds in intermediate periods.*

| Feed. | Metabolizable energy per gram of dry matter. | Percentage availability of metabolizable energy. | Available energy per gram of dry matter. |
|---|---|---|---|
| | *Calories.* | *Per cent.* | *Calories.* |
| Mixed hay | 2.057 | 56.78 | 1.168 |
| Mixed grain | 3.061 | 57.43 | 1.756 |

Applying the foregoing factors to the differences between the hay and grain consumed in the metabolism trials and in the whole periods, we may make the following computations of the protein and energy values of the rations consumed in the several periods.

### OCTOBER 1 TO DECEMBER 10, 1904.

The average feed consumption for the entire period, computed from the data contained in Tables 25 and 26, pages 62 and 63, as compared with that of the digestion trial of December 1 to 10, 1904, is shown in the following table:

TABLE 37.—*Comparison of feed consumed per day.*

| Feed. | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Whole period, Oct. 1 to Dec. 10, 1904. | | Metabolism trial, Dec. 1 to 10, 1904. | | Whole period, Oct. 1 to Dec. 10, 1904. | | Metabolism trial, Dec. 1 to 10, 1904. | |
| | Fresh weight. | Dry matter. | Fresh weight. | Dry matter. | Fresh weight. | Dry matter. | Fresh weight. | Dry matter. |
| | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Wheat bran | 250 | 217 | 254 | 219 | 176 | 153 | 180 | 156 |
| Corn meal | 749 | 626 | 761 | 634 | 528 | 442 | 540 | 450 |
| Linseed meal | 749 | 669 | 761 | 673 | 528 | 472 | 540 | 478 |
| Total grain | 1,748 | 1,512 | 1,776 | 1,526 | 1,232 | 1,067 | 1,260 | 1,084 |
| Mixed hay | 3,552 | 2,928 | 2,492 | 1,954 | 3,552 | 2,928 | 3,120 | 2,563 |

The succeeding table shows the excess or deficiency of the grain and hay consumed in the whole period as compared with the corresponding quantities in the digestion trial, and the equivalent amounts of digestible protein and of metabolizable energy computed by the use of the factors contained in Tables 35 and 36. These corrections, added to the digestible protein and metabolizable energy found in the metabolism trial give the approximate amounts of the same ingredients in the average ration of the whole period.

TABLE 38.—*Digestible protein and metabolizable energy in entire period.*

| | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Dry matter. | Digestible protein. | Metabolizable energy. | Dry matter. | Digestible protein. | Metabolizable energy. |
| | *Grams.* | *Grams.* | *Calories.* | *Grams.* | *Grams.* | *Calories.* |
| Difference in grain | − 13 | − 1.7 | − 40 | − 17 | − 2.2 | − 52 |
| Difference in hay | +974 | + 56.4 | +2,003 | +365 | + 21.1 | + 751 |
| Total correction | .......... | + 54.7 | +1,963 | .......... | + 18.9 | + 699 |
| Found in metabolism trial | .......... | 151.2 | 6,269 | .......... | 197.0 | 6,613 |
| Computed for whole period | .......... | 205.9 | 8,232 | .......... | 215.9 | 7,312 |

In this instance, the rations of the digestion trial differed quite widely as regards the ratio of hay to grain from the average ration of the period, while the results obtained, as noted, were questionable, especially as regards the nitrogen balance. (Compare pp. 192 and 197.) It will probably be more accurate, therefore, to compute the digestible protein and the energy values directly from the average daily feed consumed during the period by applying to the total dry matter of the grain and hay eaten as shown in Table 37 the same factors used above. The following are the results of this computation:

TABLE 39.—*Computed digestible protein and energy per day in entire period.*

| | Steer A. | Steer B. |
|---|---|---|
| Digestible protein ........ grams.. | 374.4 | 315.7 |
| Metabolizable energy ........ calories.. | 10,651 | 9,289 |
| Available energy ........ do.... | 6,075 | 5,294 |

### APRIL 2[1] TO JULY 15, 1905.

A comparison of the average daily feed consumed, as computed from Tables 25 and 26, with the amounts eaten during the metabolism trial of July 6 to 15, 1905, shows much smaller differences than in the period previously considered.

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[1] May 2 for steer B.

TABLE 40.—*Comparison of feed consumed per day.*

| Feed. | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Whole period, Apr. 2 to July 15, 1905. | | Metabolism trial, July 6 to 15, 1905. | | Whole period, May 2 to July 15, 1905. | | Metabolism trial, July 6 to 15, 1905. | |
| | Fresh weight. | Dry matter. | Fresh weight. | Dry matter. | Fresh weight. | Dry matter. | Fresh weight. | Dry matter. |
| | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Wheat bran | 350 | 310 | 360 | 319 | 286 | 254 | 285 | 253 |
| Corn meal | 1,050 | 914 | 1,080 | 940 | 857 | 746 | 855 | 744 |
| Linseed meal | 1,050 | 954 | 1,080 | 981 | 857 | 779 | 855 | 777 |
| Total grain | 2,450 | 2,178 | 2,520 | 2,240 | 2,000 | 1,779 | 1,995 | 1,774 |
| Mixed hay | 3,150 | 2,654 | 2,800 | 2,357 | 3,353 | 2,825 | 2,800 | 2,357 |

Correcting the results of the metabolism trial for the differences in the dry matter of grain and hay consumed as compared with the whole period, in the same manner as in the previous case, the following results are obtained:

TABLE 41.—*Digestible protein and metabolizable energy per day in entire period.*

| | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Dry matter. | Digestible protein. | Metabolizable energy. | Dry matter. | Digestible protein. | Metabolizable energy. |
| | *Grams.* | *Grams.* | *Calories.* | *Grams.* | *Grams.* | *Calories.* |
| Difference in grain | − 62 | − 8.2 | −190 | + 5 | + 0.7 | + 15 |
| Difference in hay | +297 | +18.2 | +611 | +468 | +28.7 | +963 |
| Total correction | .......... | +10.0 | +421 | .......... | +29.4 | +978 |
| Found in metabolism trial | .......... | 403.0 | 11,083 | .......... | 349.0 | 10,723 |
| Computed for whole period | .......... | 413.0 | 11,504 | .......... | 378.4 | 11,701 |

As a check upon the results of Table 41, the digestible protein and metabolizable energy has also been computed from the average amounts of dry matter consumed per day during the whole period with the following results:

TABLE 42.—*Computed digestible protein and metabolizable energy per day in entire period.*

| | Steer A. | Steer B. |
|---|---|---|
| Digestible protein: | | |
| From hay....grams.. | 162.7 | 173.2 |
| From grain....do.... | 287.5 | 234.8 |
| Total....do.... | 450.2 | 308.0 |
| Metabolizable energy: | | |
| From hay....calories.. | 5,460 | 5,811 |
| From grain....do.... | 6,667 | 5,446 |
| Total....do.... | 12,127 | 11,257 |

The fairly good agreement of the results obtained by these two methods indicates the absence of any serious error.

The difference between the percentage availability of the hay and that of the mixed grain, as shown in Table 36, is so small that for these approximate computations we may apply the average of the two results, viz, 57.11 per cent, to the total metabolizable energy of the whole ration. Computed in this way the available energy of the ration of this period as computed, on the one hand, from the corrected results of the metabolism trial, and, on the other hand, from the total dry matter consumed, is as follows: From digestion trial—Steer A, 6,570 calories; steer B, 6,682 calories. From dry matter eaten—Steer A, 6,925 calories; steer B, 6,428 calories.

### OCTOBER 6 TO DECEMBER 3, 1905.

Comparing the feed consumed in the entire period with that eaten in the digestion trial of November 13 to 22, 1905, we obtain the following results:

TABLE 43.—*Comparison of feed consumed per day.*

| Feed. | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Whole period, Oct. 6 to Dec. 3, 1905. | | Metabolism trial, Nov. 13 to 22, 1905. | | Whole period, Oct. 6 to Dec. 3, 1905. | | Metabolism trial, Nov. 13 to 22, 1905. | |
| | Fresh weight. | Dry matter. | Fresh weight. | Dry matter. | Fresh weight. | Dry matter. | Fresh weight. | Dry matter. |
| | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Wheat bran | 354 | 310 | 360 | 316 | 277 | 243 | 285 | 250 |
| Corn meal | 1,061 | 923 | 1,080 | 940 | 831 | 723 | 855 | 744 |
| Linseed meal | 1,061 | 960 | 1,080 | 978 | 831 | 752 | 855 | 774 |
| Total grain | 2,476 | 2,193 | 2,520 | 2,234 | 1,939 | 1,718 | 1,995 | 1,768 |
| Hay | 3,585 | 3,119 | 3,440 | 3,014 | 3,466 | 3,016 | 3,600 | 3,155 |

The metabolizable energy computed from the results of the metabolism trials by correcting for differences in the amounts of hay and grain consumed and that computed directly from the average dry matter eaten during the entire period are as follows:

TABLE 44.—*Digestible protein and metabolizable energy per day in entire period.*

| | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Dry matter. | Digestible protein. | Metabolizable energy. | Dry matter. | Digestible protein. | Metabolizable energy. |
| | *Grams.* | *Grams.* | *Calories.* | *Grams.* | *Grams.* | *Calories.* |
| Difference in grain | −41 | −5.3 | −126 | −50 | −6.6 | −153 |
| Difference in hay | +105 | +4.3 | +216 | −139 | −5.7 | −286 |
| Total correction | .......... | −1.0 | +90 | .......... | −12.3 | −439 |
| Found in metabolism trial | .......... | 406.6 | 12,328 | .......... | 363.1 | 11,517 |
| Computed for whole period | .......... | 405.6 | 12,418 | .......... | 350.8 | 11,078 |

TABLE 45.—*Computed digestible protein and metabolizable energy per day in entire period.*

| | | Steer A. | Steer B. |
|---|---|---|---|
| **Digestible protein:** | | | |
| From hay | grams | 128.8 | 124.6 |
| From grain | do | 289.5 | 226.8 |
| Total | do | 418.3 | 351.4 |
| **Metabolizable energy:** | | | |
| From hay | calories | 6,417 | 6,204 |
| From grain | do | 6,713 | 5,259 |
| Total | do | 13,130 | 11,463 |

The corresponding available energy, computed as before, is: From digestion trial—Steer A, 7,092 calories; steer B, 6,327 calories. From dry matter eaten—Steer A, 7,499 calories; steer B, 6,546 calories.

### APRIL 8[1] TO JULY 6, 1906.

In this period, as already noted, the ingredients of the mixed grain differed from those in the previous periods, corn-and-cob meal taking the place of corn meal, and the proportions of the single grains in the mixture being different. In the absence of any direct determinations of the energy values of the new grain mixture, however, we have used those employed in the previous three periods for the other mixtures. Tabulated as before, the comparison of the whole period with the digestion trial of June 27 to July 6, 1905, gives the results contained in the following tables:

TABLE 46.—*Comparison of feed consumed per day.*

| Feed. | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Whole period, Apr. 8 to July 6, 1906. | | Metabolism trial, June 27 to July 6, 1906. | | Whole period, Apr. 15 to July 6, 1906. | | Metabolism trial, June 27 to July 6, 1906. | |
| | Fresh weight. | Dry matter. | Fresh weight. | Dry matter. | Fresh weight. | Dry matter. | Fresh weight. | Dry matter. |
| | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Wheat bran | 590 | 511 | 635 | 550 | 438 | 379 | 460 | 398 |
| Corn-and-cob meal | [2] 1,770 | 1,525 | 1,905 | 1,641 | 1,314 | 1,132 | 1,380 | 1,189 |
| Linseed meal | 634 | 558 | 635 | 559 | 438 | 386 | 460 | 405 |
| Total grain | 2,994 | 2,594 | 3,175 | 2,750 | 2,190 | 1,897 | 2,300 | 1,992 |
| Mixed hay | 5,318 | 4,611 | 5,120 | 4,489 | 4,654 | 4,036 | 4,080 | 3,538 |

[1] April 15 for steer B.

[2] Includes 67 grams corn meal.

TABLE 47.—*Digestible protein and metabolizable energy per day in entire period.*

| | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Dry matter. | Digestible protein. | Metabolizable energy. | Dry matter. | Digestible protein. | Metabolizable energy. |
| | *Grams.* | *Grams.* | *Calories.* | *Grams.* | *Grams.* | *Calories.* |
| Difference in grain | −156 | − 15.6 | − 474 | − 95 | − 9.5 | − 291 |
| Difference in hay | +172 | + 9.6 | + 354 | +498 | + 27.7 | + 1,024 |
| Total correction | .......... | − 6.0 | − 120 | .......... | + 18.2 | + 733 |
| Found in metabolism trial | .......... | 450.4 | 16,827 | .......... | 380.9 | 12,701 |
| Computed for whole period | .......... | 444.4 | 16,707 | .......... | 399.1 | 13,434 |

TABLE 48.—*Computed digestible protein and metabolizable energy per day for entire period.*

| | Steer A. | Steer B. |
|---|---|---|
| Digestible protein: | | |
| From hay ... grams | 256.8 | 224.8 |
| From grain ... do | 259.9 | 190.1 |
| Total ... do | 516.7 | 414.9 |
| Metabolizable energy: | | |
| From hay ... calories | 9,485 | 8,302 |
| From grain ... do | 7,940 | 5,807 |
| Total ... do | 17,425 | 14,109 |

The available energy, computed as before, is: From digestion trial—Steer A, 9,542 calories; steer B, 7,673 calories. From dry matter eaten—Steer A, 9,952 calories; steer B, 8,058 calories.

### OCTOBER 26 TO DECEMBER 15, 1906.

No digestion and metabolism trials were made during this period. We are compelled, therefore, to compute the digestible protein and the available energy of the average daily ration from the total amounts consumed by the use of average factors.

The average daily ration which was consumed during this period is shown in the table below. The mixed hay, wheat bran, and corn-and-cob meal are assumed to have contained the same percentage of dry matter as in the previous period and the air-dry corn silage to contain 90 per cent of dry matter.

TABLE 49.—*Average feed consumed per day.*

| Feed. | Steer A. | | Steer B. | |
|---|---|---|---|---|
| | Fresh weight. | Dry matter. | Fresh weight. | Dry matter. |
| | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Mixed hay | 3,812 | 3,305 | 3,212 | 2,785 |
| Corn silage (air-dry weight) | 1,118 | 963 | 1,118 | 963 |
| Wheat bran | 693 | 600 | 669 | 579 |
| Corn-and-cob meal | 1,386 | 1,247 | 1,339 | 1,205 |

For the wheat bran we may assume the same protein and energy values as were found in the respiration-calorimeter experiments of 1905, and for the mixed hay the averages used in computing the last previous period, as follows:

| | | |
|---|---|---|
| Digestible protein: | | |
| Wheat bran | per cent.. | 11.18 |
| Mixed hay | do.... | 5.57 |
| Available energy per gram of dry matter: | | |
| Wheat bran | calories.. | 1.392 |
| Mixed hay | do.... | 1.168 |

No determinations of the available energy of corn-and-cob meal are on record. A calculation based on the composition as shown in Table 26, using Jordan's coefficients of digestibility and Kellner's factors for energy and assuming a "Wertigkeit" of 90 per cent, gives the following approximate values: Digestible protein, 3.93 per cent; available energy per gram dry matter, 1.76 calories.

For the silage, we have used the digestible protein and available energy computed for average American corn silage in Farmers' Bulletin 346 of the United States Department of Agriculture, viz, digestible protein in dry matter, 4.73 per cent; available energy per gram of dry matter, 1.426 calories.

Using these estimates, the average daily ration as stated above contained:

TABLE 50.—*Computed digestible protein and metabolizable energy per day for entire period.*

| Feed. | Steer A. | | Steer B. | |
|---|---|---|---|---|
| | Digestible protein. | Available energy. | Digestible protein. | Available energy. |
| | *Grams.* | *Calories.* | *Grams.* | *Calories.* |
| Mixed hay | 184.1 | 3,861 | 155.1 | 3,253 |
| Corn silage | 45.6 | 1,373 | 45.6 | 1,373 |
| Wheat bran | 67.1 | 835 | 67.7 | 806 |
| Corn-and-cob meal | 49.0 | 2,195 | 47.4 | 2,121 |
| | 345.8 | 8,264 | 315.8 | 7,553 |

### SUMMARY OF AVERAGE RATIONS IN THE INTERMEDIATE FEEDING PERIODS.

The foregoing computations of the digestible protein and available energy of the average daily rations in the several periods of the general feeding are summarized in the following table:

TABLE 51.—*Summary of average daily rations per head.*

| Periods. | Steer A. | | Steer B. | |
|---|---|---|---|---|
| | Digestible protein. | Available energy. | Digestible protein. | Available energy. |
| | *Grams.* | *Calories.* | *Grams.* | *Calories.* |
| Oct. 1 to Dec. 10, 1904 | 374.4 | 6,075 | 315.7 | 5,294 |
| Apr. 2 to July 15, 1905 | 413.0 | 6,570 | .......... | .......... |
| May 2 to July 15, 1905 | .......... | .......... | 378.4 | 6,682 |
| Oct. 6 to Dec. 3, 1905 | 405.6 | 7,092 | 350.8 | 6,327 |
| Apr. 8 to July 6, 1906 | 444.4 | 9,542 | .......... | .......... |
| Apr. 15 to July 6, 1906 | .......... | .......... | 399.1 | 7,673 |
| Oct. 26 to Dec. 15, 1906 | 345.8 | 8,264 | 315.8 | 7,553 |

## NUTRITIVE EFFECT OF RATIONS.

### GAINS IN LIVE WEIGHT.

The following table shows the live weights most nearly corresponding to the beginning and end of each of the periods into which the intermediate feeding was divided, as shown in Table 25. The weights, except where otherwise noted, are the average of three or five consecutive daily weighings, regarded as representing the average weight on the middle day. Dates have been selected on which such averages could be taken and, therefore, they do not in all cases correspond exactly with those of Table 25 showing the feed consumed. The differences in this respect are so small, however, that we may safely compare the daily averages of feed consumed and gains made without fearing the introduction of any sensible error.

TABLE 52.—*Gains in live weight in intermediate feeding periods.*

| Periods. | Number of days. | Initial weight of steer. | Final weight of steer. | Total gain. | Gain per day. | Daily gain per 1,000 mean weight. |
|---|---|---|---|---|---|---|
| *Steer A.* | | *Kilos.* | *Kilos.* | *Kilos.* | *Kilos.* | *Kilos.* |
| Oct. 1 to Dec. 11, 1904 | 71 | 246.5 | 280.7 | 34.2 | 0.482 | 1.828 |
| Mar. 31 to July 13, 1905 | 104 | 277.0 | 314.3 | 37.3 | .359 | 1.262 |
| July 13 to Sept. 28, 1905 | 77 | 314.3 | 360.0 | 45.7 | .594 | 1.762 |
| Sept. 28 to Nov. 28, 1905 | 61 | 360.0 | 387.3 | 27.3 | .448 | 1.199 |
| Apr. 6 to July 4, 1906 | 89 | 403.2 | 456.1 | 52.9 | .594 | 1.382 |
| July 4 to July 28, 1906 | 24 | 456.1 | [1] 456.6 | .5 | .021 | .046 |
| July 28 to Oct. 27, 1906 | 91 | [1] 456.6 | [1] 466.8 | 10.2 | .112 | .243 |
| Oct. 27 to Dec. 4, 1906 | 39 | [1] 466.8 | 495.1 | 28.3 | .726 | 1.509 |
| Apr. 30 to Oct. 28, 1907 | 181 | 527.8 | [1] 594.2 | 66.4 | .367 | .654 |
| Oct. 28 to Jan. 4, 1908 | 68 | [1] 594.2 | [1] 632.8 | 38.6 | .568 | .926 |
| Totals and means: | | | | | | |
| Oct. 1, 1904 to Dec. 4, 1906 | 555 | ........ | ........ | 296.4 | .426 | 1.149 |
| Oct. 1, 1904, to Jan. 4, 1908 | 825 | ........ | ........ | 341.4 | .414 | .942 |
| *Steer B.* | | | | | | |
| Oct. 1 to Dec 11, 1904 | 71 | 171.0 | 215.0 | 44.0 | .620 | 3.213 |
| May 5 to July 13, 1905 | 69 | 195.0 | 233.6 | 38.6 | .559 | 2.608 |
| July 13 to Sept. 28, 1905 | 77 | 233.6 | 263.5 | 29.9 | .388 | 1.561 |
| Sept. 28 to Nov. 28, 1905 | 61 | 263.5 | 296.8 | 33.3 | .546 | 1.949 |
| Apr. 13 to July 4, 1906 | 82 | 307.9 | 343.1 | 35.2 | .429 | 1.318 |
| July 4 to July 28, 1906 | 24 | 343.1 | [1] 335.4 | —7.7 | —.321 | —.946 |
| July 28 to Oct. 27, 1906 | 91 | [1] 335.4 | [1] 363.2 | 27.8 | .305 | .873 |
| Oct. 27 to Dec. 4, 1906 | 39 | [1] 363.2 | 379.2 | 16.0 | .410 | 1.105 |
| Apr. 26 to Oct. 28, 1907 | 185 | 384.1 | [1] 428.6 | 44.5 | .241 | .593 |
| Oct. 28 to Jan. 4, 1908 | 68 | [1] 428.6 | [1] 483.1 | 54.5 | .801 | 1.757 |
| Totals and means: | | | | | | |
| Oct. 1, 1904, to Dec. 4, 1906 | 514 | ........ | ........ | 217.1 | .422 | 1.875 |
| Oct. 1, 1904, to Jan. 4, 1908 | 767 | ........ | ........ | 316.1 | .412 | 1.260 |

[1] Single weighing.

In five periods out of nine, omitting the doubtful period of July 4 to 28, 1906, steer B shows a somewhat greater gain per head and a notably greater gain per 1,000 kilograms live weight than steer A, but taking the experiments as a whole, little difference appears in the average daily gain in live weight per head. The average daily gain per 1,000 kilograms up to December 4, 1906, which terminates that portion of the intermediate feeding for which exact feeding records were kept, is 63 per cent greater by steer B than by steer A. If we include in the comparison the summer pasturage in

1907 and the period of fattening during the succeeding winter, the difference is reduced to 34 per cent.

### FEED CONSUMED PER UNIT OF GAIN.

The feed consumed in the foregoing periods is recorded in Table 25, but the amount of air-dry matter eaten may be repeated here for readier comparison with the gains in live weight. Table 53 shows the average daily consumption of air-dry feed per head and also the amount eaten per 1,000 kilograms live weight, computed both directly in proportion to the weight and in proportion to the two-thirds power of the live weight, i. e., to the surface.

TABLE 53.—*Air-dry feed eaten.*

| Periods. | Feed consumed per day. | | | Feed consumed per kilogram gain in live weight. |
|---|---|---|---|---|
| | Per head. | Per 1,000 kilograms average live weight. | | |
| | | W. | $W^{\frac{2}{3}}$. | |
| *Steer A.* | *Kilos.* | *Kilos.* | *Kilos.* | *Kilos.* |
| Oct. 1 to Dec. 11, 1904 | 5.30 | 20.11 | 12.89 | 11.00 |
| Mar. 31 to July 13, 1905 | 5.60 | 18.84 | 12.55 | 15.52 |
| July 13 to Sept. 28, 1905 | 5.07 | 14.35 | 9.99 | 8.15 |
| Sept. 28 to Nov. 28, 1905 | 6.06 | 16.32 | 11.76 | 13.62 |
| Apr. 6 to July 4, 1906 | 8.31 | 19.34 | 14.59 | 13.99 |
| July 4 to 28, 1906 | 4.30 | 9.40 | 7.24 | [204.30] |
| July 28 to Oct. 27, 1906 | 4.45 | 9.64 | 7.45 | 39.73 |
| Oct. 27 to Dec. 4, 1906 | 7.01 | 14.57 | 11.42 | 9.66 |
| Average | 5.85 | 15.73 | 11.31 | 13.68 |
| *Steer B.* | | | | |
| Oct. 1 to Dec. 11, 1904 | 4.78 | 24.51 | 14.17 | 7.63 |
| May 5 to July 13, 1905 | 5.35 | 24.34 | 14.59 | 9.60 |
| July 13 to Sept. 28, 1905 | 4.55 | 17.44 | 10.96 | 10.96 |
| Sept. 28 to Nov. 28, 1905 | 5.40 | 19.31 | 12.63 | 9.91 |
| Apr. 13 to July 4, 1906 | 6.84 | 21.10 | 14.52 | 16.01 |
| July 4 to 28, 1906 | 4.11 | 11.81 | 8.26 | ........ |
| July 28 to Oct. 27, 1906 | 4.48 | 12.83 | 9.03 | 14.69 |
| Oct. 27 to Dec. 4, 1906 | 6.34 | 17.08 | 12.27 | 15.46 |
| Average | 5.28 | 18.98 | 12.34 | 12.37 |

The greater consumption of coarse feed by steer B on the limited grain ration has already been noted and is reflected in the foregoing table. While the air-dry matter consumed per head is greater in the case of steer A, the consumption is relatively greater by steer B, whether calculated in proportion to the weight or surface, with a single exception in the latter case. Accompanying this greater consumption of feed by steer B we find (omitting the doubtful period, July 4 to 28, 1906) that in four cases out of the seven, steer B produced a unit of gain in live weight on less air-dry feed than did steer A, the average of the whole time being decidedly in favor of the former animal. Judged merely from the standpoint of the increase in live weight therefore, steer B appears to have been on the whole a more economical producer than steer A up to December 4, 1906. On pasture during the following summer, however, steer

A gained 50 per cent faster per head than did steer B and a little more rapidly per 1,000 kilograms live weight. Steer A reached a greater final weight than steer B, because he started the experiment with the advantage of weight in his favor. He had more internal machinery to work with, but the figures do not indicate that the machinery worked any more efficiently in the production of increase in live weight. Whatever advantage, if any, steer A had over steer B in the economical production of live weight in relation to total feed consumed apparently manifested itself in the earlier periods of his life before the beginning of this investigation.

### THE PRODUCTION OF PROTEIN TISSUE.

The four respiration calorimeter experiments each winter necessarily included determinations of the nitrogen balance. In one of these four periods (Period II) the ration was largely in excess of the maintenance requirement, while in the experiments of 1906 and 1907, the rations of steer A in Period I likewise proved to be materially above maintenance. We may therefore presume that in these periods the animals made a normal gain of protein, since the protein supply in the ration was fairly liberal. In addition to these periods, the digestion trials made on each animal during the intermediate feeding periods included determinations of income and outgo of nitrogen, so that in all we have nine nitrogen balances for steer A and seven for steer B, exclusive of those on maintenance or submaintenance rations. The dates of these trials and the rations consumed are brought together for convenience, in the following table:

TABLE 54.—*List of nitrogen balances.*

| Date of trial. | Steer A—Daily ration. | | | | Date of trial. | Steer B—Daily ration. | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Hay. | Wheat bran. | Corn meal. | Linseed meal. | | Hay. | Wheat bran. | Corn meal. | Linseed meal. |
| | *Grams.* | *Grams.* | *Grams.* | *Grams.* | | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Dec. 1 to 10, 1904 | [1] 3,629 | 254 | 761 | 761 | Dec. 2 to 10, 1904 | [1] 3,629 | 180 | 540 | 540 |
| Feb. 9 to 18, 1905 | [2] 2,250 | 3,000 | ........ | ........ | Apr. 27 to May 6, 1905 | [2] 2,000 | 2,000 | ........ | ........ |
| July 6 to 15, 1905 | [1] 2,800 | 360 | 1,080 | 1,080 | July 6 to 15, 1905 | [1] 2,800 | 285 | 855 | 855 |
| Nov. 13 to 22, 1905 | [1] 3,440 | 360 | 1,080 | 1,080 | Nov. 13 to 22, 1905 | [1] 3,600 | 285 | 855 | 855 |
| Jan. 18 to 27, 1906 | [2] 3,000 | 300 | 900 | 900 | Feb. 23 to Mar. 3, 1906 | [2] 2,800 | 357 | 1,072 | 1,071 |
| Feb. 15 to 24, 1906 | [2] 3,000 | 700 | 2,100 | 2,100 | June 27 to July 6, 1906 | [1] 4,080 | 460 | [3] 1,380 | 460 |
| June 27 to July 6, 1906 | [1] 5,120 | 635 | [3] 1,905 | 635 | Mar. 7 to 16, 1907 | [2] 3,200 | 450 | 1,350 | 1,350 |
| Jan. 31 to Feb. 9, 1907 | 3,400 | 335 | 1,000 | 1,000 | | | | | |
| Feb. 28 to Mar 9, 1907 | [2] 3,400 | 800 | 2,400 | 2,400 | | | | | |

[1] Mixed clover and timothy hay. [2] Timothy hay. [3] Corn-and-cob meal.

The succeeding table summarizes the daily gain or loss of nitrogen by the animals in the foregoing periods, as shown by the detailed records of Part II, and the corresponding amounts of protein, obtained by multiplication of the nitrogen by the factor 6.0, while the protein has also been computed per 1,000 kilograms in direct proportion to the live weight.

TABLE 55.—*Gains of nitrogen and protein.*

| Date of trial. | Age of steer. | Average live weight. | Gains of nitrogen. | Equivalent protein— Per head. | Equivalent protein— Per 1,000 kilos live weight. |
|---|---|---|---|---|---|
| *Steer A.* | *Months.* | *Kilos.* | *Grams.* | *Grams.* | *Grams.* |
| Dec. 1 to 10, 1904 | 11 | 278.3 | − 39.7 | − 238.2 | − 856.0 |
| Feb. 9 to 18, 1905 | 13 | 279.1 | + 1.8 | + 10.8 | + 38.7 |
| July 6 to 15, 1905 | 18 | 312.3 | + 4.4 | + 26.4 | + 84.5 |
| Nov. 13 to 22, 1905 | 22 | 379.3 | + 2.9 | + 17.4 | + 45.9 |
| Jan. 18 to 27, 1906 | 24 | 404.0 | + 3.2 | + 19.2 | + 47.5 |
| Feb. 15 to 24, 1906 | 25 | 420.7 | − 5.7 | − 34.2 | − 81.3 |
| June 27 to July 6, 1906 | 30½ | 451.4 | − 1.5 | − 9.0 | − 19.9 |
| Jan. 31 to Feb. 9, 1907 | 36½ | 498.6 | + 1.1 | + 6.6 | + 13.2 |
| Feb. 28 to Mar. 9, 1907 | 38½ | 518.7 | + 3.6 | + 21.6 | + 41.6 |
| *Steer B.* | | | | | |
| Dec. 2 to 10, 1904 | 13 | 215.5 | − 25.4 | − 152.4 | − 707.1 |
| Apr. 27 to May 6, 1905 | 15 | 196.9 | + 11.6 | + 69.6 | + 353.5 |
| July 6 to 15, 1905 | 20 | 232.4 | + 6.3 | + 37.8 | + 162.6 |
| Nov. 13 to 22, 1905 | 24 | 288.0 | + 5.4 | + 32.4 | + 112.5 |
| Feb. 23 to Mar. 3, 1906 | 28 | 309.6 | − 1.2 | − 7.2 | − 23.3 |
| June 27 to July 6, 1906 | 32 | 340.9 | + 2.6 | + 15.6 | + 45.8 |
| Mar. 7 to 16, 1907 | 40 | 386.4 | + 9.6 | + 57.6 | + 149.1 |

It is evident from the foregoing table that the results as regards protein are decidedly irregular. Those obtained in the first digestion trial (Dec. 1 to 10, 1904), as already noted, are plainly erroneous, owing in part to the abnormally low consumption of feed during those trials and in part probably to some undetected error. In the digestion trial of June 27 to July 6, 1906, as pointed out on page 198, some extraneous cause seems to have affected the protein katabolism, causing a marked increase during the 10 days on which the nitrogen balance was determined. It seems probable, therefore, that the gain of nitrogen shown by the tables is lower in this trial than properly corresponds to the feed consumed. We are unable to account for the negative nitrogen balances in the respiration calorimeter experiments of February 15 to 24 and February 24 to March 2, 1906.

Omitting the first digestion trial and accepting the results of the others as they stand, figure 12 shows the gain of protein in grams per 1,000 kilograms live weight. With the exception of the apparently abnormal gain by steer B in the trial from April 27 to May 6, 1905, the results on the two animals, notwithstanding their apparently capricious character, show a rather striking parallelism, falling to a minimum in the trial of February, 1906, and rising to approximately the original level in the last trial. The cause of this behavior is not obvious. It does not seem to be directly related to the protein supply in the feed. Table 56 shows the digestible protein of the rations per head and also computed per 1,000 kilograms in proportion to the live weight. The minimum protein requirement for the maintenance of the nitrogen equilibrium of cattle may be estimated at not far from 500 grams per 1,000 kilograms live weight. Subtracting this amount from the digestible protein per 1,000 kilograms gives, in the fifth column of the table, the amount of protein available for the production of gain of flesh, while the sixth, or last, column shows the percentage of this surplus actually stored up in the body of the animal according to the figures of Table 55.

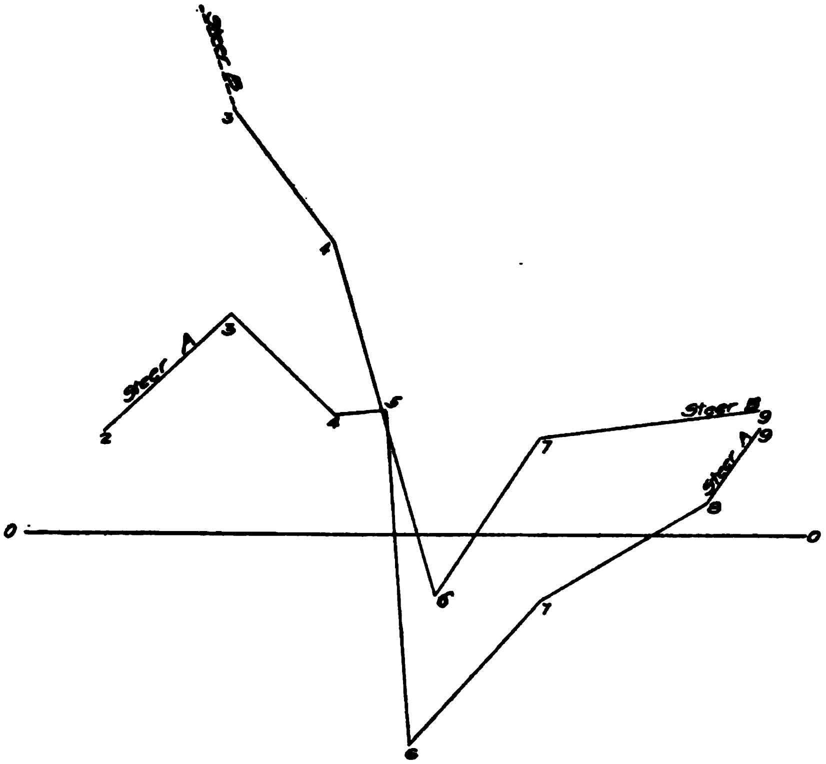

FIG. 12.—Gain of protein per 1,000 kilograms live weight.

TABLE 56.—*Digested protein of rations in digestion and metabolism trials.*

| Date of trial. | Age of steer. | Per head. | Per 1,000 kilos live weight. Total. | Per 1,000 kilos live weight. Surplus after deducting maintenance. | Percentage of surplus stored in body. |
|---|---|---|---|---|---|
| *Steer A.* | *Months.* | *Grams.* | *Grams.* | *Grams.* | *Per cent.* |
| Feb. 9 to 18, 1905 | 13 | 293.1 | 1,050.2 | 550.2 | 7.0 |
| July 6 to 15, 1905 | 18 | 403.0 | 1,290.3 | 790.3 | 10.67 |
| Nov. 13 to 22, 1905 | 22 | 406.6 | 1,072.0 | 572.0 | 8.02 |
| Jan. 18 to 27, 1906 | 24 | 315.8 | 781.7 | 281.7 | 16.86 |
| Feb. 15 to 24, 1906 | 25 | 530.5 | 1,261.0 | 761.0 | − 10.68 |
| June 27 to July 6, 1906 | 30½ | 450.4 | 997.8 | 497.8 | − 4.00 |
| Jan. 31 to Feb. 9, 1907 | 36½ | 353.9 | 709.8 | 209.8 | 6.29 |
| Feb. 28 to Mar. 9, 1907 | 38½ | 725.4 | 1,398.3 | 898.3 | 4.63 |
| *Steer B.* | | | | | |
| Apr. 27 to May 6, 1905 | 15 | 218.3 | 1,108.7 | 608.7 | 58.08 |
| July 6 to 15, 1905 | 20 | 349.0 | 1,501.7 | 1,001.7 | 16.22 |
| Nov. 13 to 22, 1905 | 24 | 363.1 | 1,260.7 | 760.7 | 14.79 |
| Feb. 23 to Mar. 3, 1906 | 28 | 318.1 | 1,027.4 | 527.4 | − 4.42 |
| June 27 to July 6, 1906 | 32 | 380.9 | 1,117.3 | 617.3 | 7.42 |
| Mar. 7 to 16, 1907 | 40 | 467.9 | 1,211.0 | 711.0 | 20.97 |

Figure 13 shows graphically the surplus protein supply per 1,000 kilograms live weight in each period. A comparison with figure 12, representing the gains of protein, shows no obvious relation between the two.

The results recorded in the last column of Table 56 as to the percentage of the surplus protein retained in the body are expressed graphically in figure 14. The percentage retention in the case of steer A in the trial of January 18 to 27, 1906, is relatively high. No corresponding result is available on steer B for the reason that the energy of his total ration in that period was below the maintenance requirement, and a material loss of fat from the body of the animal took place. If we disregard this one result for steer A and consider the broken line in the diagram to represent the course of his protein gains between the trials of November, 1905, and February, 1906, we find the same general parallelism between the results on the two animals as in the case of the absolute gains. The rations fed were lower in protein than was intended. The computed surplus of protein above

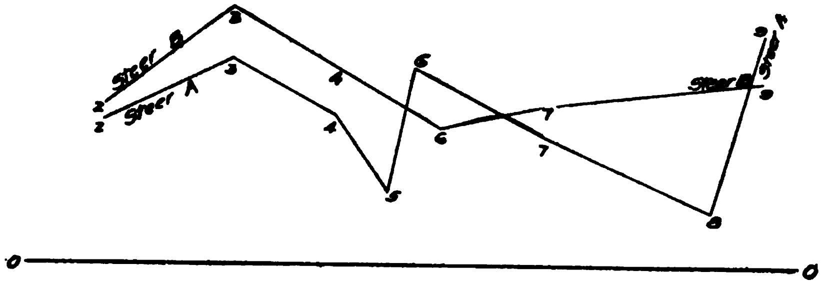

FIG. 13.—Surplus protein per 1,000 kilograms live weight.

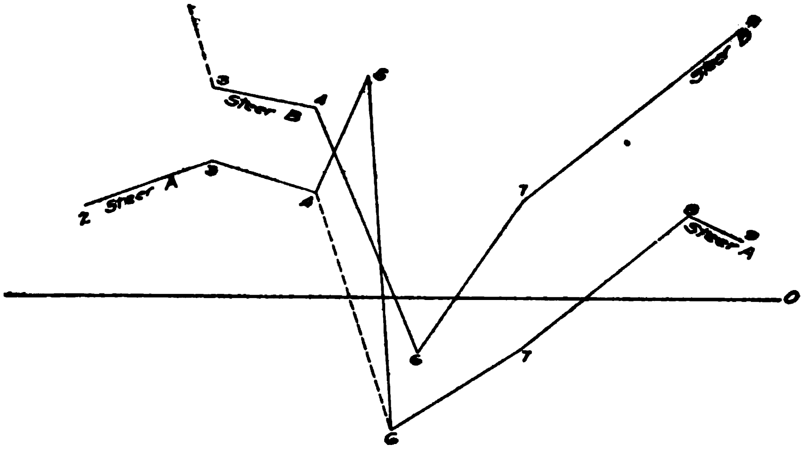

FIG. 14.—Percentage of surplus protein retained in body.

the estimated maintenance requirement is in most cases greater with steer B than with steer A, but the fact that in the case of the former animal a higher percentage of this larger supply was retained would not indicate that the somewhat more liberal supply of protein in the feed of steer B was the cause of his greater gain, nor that the protein supply was the limiting factor of the gain of protein tissue by steer A.

We may say, then, that the relative gain of protein by the animals and the percentage of the surplus feed protein which was retained in the body run, in general, parallel in the two animals, but that steer B was superior to steer A in both respects. In spite of some irregularity in the results, therefore, they seem to indicate quite clearly that steer B possessed a greater tendency to growth of protein tissue than did steer A.

### ENERGY STORAGE—CHARACTER OF GAIN IN LIVE WEIGHT.

It has been shown on pages 78 to 80 that steer B made relatively greater gains in live weight than did steer A and required on the average a smaller weight of air-dry feed to produce a unit of gain. The differences in the character of the growth of the two animals, however, as revealed by the measurements and photographs taken and confirmed by the results of the block test would prepare one to expect that a unit gain in live weight might differ widely at different times and with the two animals, both as to chemical composition and as to the amount of energy storage which it represented, and therefore as to its value as human food. The comparisons now to be presented appear to confirm this expectation.

### RELATIVE GAIN OF PROTEIN.

It has been shown in some detail in preceding paragraphs that steer B showed a distinctly greater tendency toward gain of protein tissue than did steer A. A gain of protein, however, represents the storage of much less energy than that of a corresponding weight of fat, and, moreover, a gain of protein implies the deposition along with it of three or four times its weight of water. The tendency of the apparently greater ability of steer B to store up protein, therefore, would be to make his gain in live weight relatively more rapid than that of steer A on equivalent rations. Part of this difference may be plausibly accounted for by his greater increase in length and height with the accompanying increase in those structural tissues such as bones, ligaments, tendons, skin, etc., which consist largely of protein.

### PROPORTION OF FAT TO PROTEIN IN INCREASE.

In the respiration calorimeter experiments we have data as to the proportions of protein and fat gained. A comparison of the record shows that in every case in which there was a gain of both protein and fat the ratio of the former to the latter was notably smaller with steer A than with steer B. This is also shown by the following tabulation, in which the composition of the ash-free increase is computed from the data contained in Part II, assuming fresh lean meat to contain 3.55 per cent nitrogen. The table includes also two cases of a negative nitrogen balance, illustrating the greater gain of fat by steer A in these cases also.

TABLE 57.—*Computed composition of ash-free gain.*

| | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Weight. | | Per cent. | | Weight. | | Per cent. | |
| | Flesh. | Fat. | Flesh. | Fat. | Flesh. | Fat. | Flesh. | Fat. |
| *Experiments of 1905.* | *Grams.* | *Grams.* | *Per cent.* | *Per cent.* | *Grams.* | *Grams.* | *Per cent.* | *Per cent.* |
| Period II | 50.7 | 112.5 | 31.06 | 68.94 | 326.8 | 54.6 | 85.69 | 14.31 |
| *Experiments of 1906.* | | | | | | | | |
| Period I | 90.1 | 135.0 | 40.03 | 59.97 | .......... | .......... | .......... | .......... |
| Period II | −160.6 | 469.2 | .......... | .......... | − 33.8 | 122.6 | .......... | .......... |
| *Experiments of 1907.* | | | | | | | | |
| Period I | 31.0 | 175.7 | 15.00 | 85.00 | .......... | .......... | .......... | .......... |
| Period II | 101.4 | 657.3 | 13.36 | 86.64 | 270.4 | 243.8 | 52.59 | 47.41 |
| Period IV | − 42.3 | 70.3 | .......... | .......... | − 67.6 | 23.9 | .......... | .......... |

The corresponding energy content of one kilogram of the ash-free gain, computed by the use of the customary factors, is as follows:

TABLE 58.—*Energy content of 1 kilogram of ash-free gain.*

| | Steer A. | Steer B. |
|---|---|---|
| *Experiments of 1905.* | *Calories.* | *Calories.* |
| Period II | 6,926 | 2,399 |
| *Experiments of 1906.* | | |
| Period I | 6,183 | .......... |
| *Experiments of 1907.* | | |
| Period I | 8,257 | .......... |
| Period II | 8,393 | 5,143 |

It is of course true that the foregoing comparisons are probably affected by the total amount of feed eaten. In the corresponding periods steer A consumed heavier rations than steer B, and this would tend to increase the production of fat relatively to that of protein tissue. The results are cited as indications rather than proofs of the difference in the character of the gains in the two animals. It is to be noted, however, that in the experiments of 1907 the ration of steer A in Period I and that of steer B in Period II were approximately equal in amount, and in this case the energy content of 1 kilogram of gain is notably greater with steer A.

Another indication of the greater proportion of fat in the gain made by steer A was obtained in connection with the block test. In the fattening preliminary to this test it was impossible to bring steer B into as good condition as steer A, the latter being graded as "prime," while steer B was graded as "common." Steer B produced somewhat less internal fat than steer A, and his subcutaneous fat tissue was much less fully developed. In technical phrasing, his carcass was not well covered. The following table illustrates these differences:

TABLE 59.—*Proportion of fat in carcasses.*

| Animals. | Live weight. | Dressed weight. | Per cent of live weight. | | |
|---|---|---|---|---|---|
| | | | Suet in loin. | Paunch and intestinal fat. | Pluck fat. |
| | *Pounds.* | *Pounds.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Steer A | 1,395 | 837.75 | 2.426 | 0.910 | 5.02 |
| Steer B | 1,065 | 580.25 | .962 | .658 | 4.60 |

The lean meat of both steers was "marbled," but that of steer A to a much greater extent than that of steer B. It was not possible to analyze the carcasses of the two animals, but samples of the lean meat of the porterhouse and round of each animal were analyzed by Mr. W. W. Braman,[1] with the following results, the energy being computed in the same manner as before. The results show a marked difference in the energy content of the lean meat of the two animals.

TABLE 60.—*Composition of fresh lean meat.*

| | Porterhouse cut. | | Round cut. | |
|---|---|---|---|---|
| | Steer A. | Steer B. | Steer A. | Steer B. |
| Total nitrogen ........ per cent.. | 3.407 | 3.488 | 3.496 | 3.616 |
| Fat ........ do.... | 12.71 | 6.72 | 6.66 | 3.34 |
| Energy per kilogram ........ calories.. | 2,372 | 1,831 | 1,829 | 1,554 |

### ENERGY CONTENT OF GAIN IN LIVE WEIGHT.

The foregoing results agree in indicating that a unit of gain in live weight by steer A contained more potential energy than in the case of steer B. The data contained in Table 51 regarding the available energy of the average daily rations consumed afford a further test of this supposition.

The available energy of a feeding stuff or ration, in the sense in which the term is here used, signifies that portion of its total energy which can be used on the one hand to prevent a loss of the stored-up energy of the body or, on the other hand, when supplied in excess of the maintenance requirement, is stored up as gain of flesh and fat. If, then, from the available energy of the rations as recorded in Table 51, we deduct the available energy required for maintenance, the remainder will represent the amount of energy capable of being stored up in the body as the potential energy of protein and fat. In the following table this computation has been made. The maintenance requirements are those computed on page 55, viz, per 500 kilograms live weight, for steer A, 5,971 calories, and for steer B, 7,090 calories. The actual maintenance requirement per day in each case has been computed in proportion to the two-thirds power of the live weight on the basis of the average live weight for the period as shown in the first column of the table. Dividing the estimated daily gain of energy by the average daily gain in live weight gives in the last column the total energy content of 1 kilogram of gain.

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[1] "The Influence of Fattening upon the Composition of the Lean Meat of Cattle," thesis for the degree of M. S., 1908.

TABLE 61.—*Energy content of gain in live weight.*

| Date of trial. | Average live weight.[1] | Available energy per day. | Estimated maintenance requirement. | Estimated gain of energy. | Average daily gain in weight. | Energy in 1 kilogram gain. |
|---|---|---|---|---|---|---|
| *Steer A.* | *Kilos.* | *Calories.* | *Calories.* | *Calories.* | *Kilos.* | *Calories.* |
| Oct. 1 to Dec. 10, 1904 | 263.6 | 6,075 | 3,897 | 2,178 | 0.482 | 4,519 |
| Apr. 2 to July 15, 1905 | 295.7 | 6,570 | 4,207 | 2,363 | .359 | 6,583 |
| Oct. 6 to Dec. 3, 1905 | 373.7 | 7,092 | 4,918 | 2,174 | .448 | 4,853 |
| Apr. 8 to July 6, 1906 | 429.7 | 9,542 | 5,397 | 4,145 | .594 | 6,978 |
| Oct. 26 to Dec. 15, 1906 | 481.0 | 8,264 | 5,818 | 2,446 | [2] .726 | 3,369 |
| *Steer B.* | | | | | | |
| Oct. 1 to Dec. 10, 1904 | 193.0 | 5,294 | 3,760 | 1,534 | .620 | 2,474 |
| May 2 to July 15, 1905 | 214.3 | 6,682 | 4,030 | 2,652 | .559 | 4,744 |
| Oct. 6 to Dec. 3, 1905 | 280.2 | 6,327 | 4,819 | 1,508 | .546 | 2,762 |
| Apr. 15 to July 6, 1906 | 325.5 | 7,673 | 5,326 | 2,347 | .429 | 5,471 |
| Oct. 26 to Dec. 15, 1906 | 371.2 | 7,553 | 5,813 | 1,740 | [2] .410 | 4,244 |

[1] Average of initial and final weights as recorded in Table 52 for the period corresponding most nearly to the feeding period.

[2] Initial weight in this period is from a single weighing.

The data of Table 61, as well as the graphic representation of the results in figure 15, show that with the exception of the last period, in which the true gain of weight is somewhat uncertain, steer A appeared notably superior to steer B as regards the energy content of a unit of gain. We can hardly err in ascribing this difference largely to the greater proportion of protein and accompanying water which appears to have characterized the gain made by steer B.

Another interesting point brought out by these results is an apparent seasonal variation in the energy content of the gain, it being greatest in the spring months and least in the fall months.

None of the foregoing results can, of course, be interpreted as constituting a quantitative determination of the composition or energy value of the gains in live weight. Taken together, however, they seem to be fairly conclusive as to the qualitative nature of the difference in this respect between the two animals and to furnish an adequate explanation of the apparent discrepancy between the results of the determinations of digestibility and availability of the feed, on the one hand, and the relatively greater gain of live weight by steer B on the other hand.

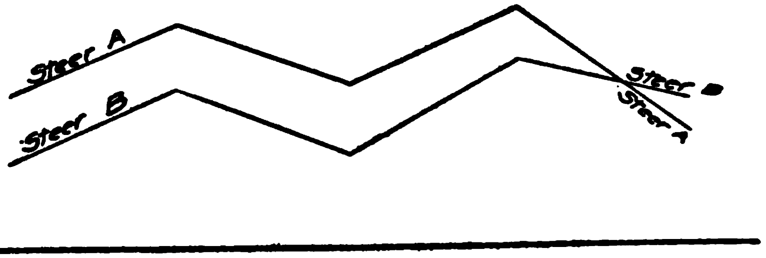

FIG. 15.—Energy content of 1 kilogram gain in live weight.

## FEED REQUIREMENTS FOR GROWTH.

It is of interest to compare the rations consumed and the gains made by these two steers with the accepted feed requirements of such animals as formulated in the current tables of "feeding standards" for growing cattle. The most recent and generally accepted of these are Kellner's [1] which are expressed in terms of digestible protein and "starch values," 1 kilogram starch value being equivalent to 2,356 calories of energy value. Kellner's standards are as follows, the starch values being reduced to their equivalents in energy value expressed in "therms."[2]

TABLE 62.—*Kellner's feeding standards for growing cattle.*

| Age in months. | Average live weight per head. | Requirements per 1,000 kilos live weight. | |
|---|---|---|---|
| | | Digestible protein. | Energy values. |
| *Dairy breeds.* | *Kilos.* | *Kilos.* | *Therms.* |
| 3 to 6 | 140 | 2.80 | 35.81 |
| 6 to 12 | 240 | 2.30 | 27.10 |
| 12 to 18 | 320 | 1.80 | 21.20 |
| 18 to 24 | 400 | 1.30 | 18.85 |
| *Beef breeds.* | | | |
| 3 to 6 | 150 | 3.50 | 38.88 |
| 6 to 12 | 250 | 2.80 | 31.81 |
| 12 to 18 | 350 | 2.20 | 23.56 |
| 18 to 24 | 430 | 1.50 | 21.20 |

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[1] "Die Ernährung der landwirtschaftl. Nutztiere.," 5th ed., p. 615.

[2] A therm equals 1,000 kilogram calories.

The live weight of steer A at the beginning of the investigation corresponded with the weight assumed by Kellner for animals of the same age, being, if anything, a trifle higher, but the weight of steer B was considerably less. The later weights of the two steers can not be compared with those predicated by Kellner for the corresponding ages on account of the respiration calorimeter experiments, covering about three months of each year, during which light rations were fed and little or no growth made. We may, however, compare our results with those expected to be obtained by the use of Kellner's standards by computing the average daily rate of gain in the intermediate feeding periods. From Kellner's figures, as given in Table 62, the expected gain per day and head may be computed as follows:

| | Dairy breeds. | Beef breeds. |
|---|---|---|
| | *Kilos.* | *Kilos.* |
| Between 4½ and 9 months | 0.392 | 0.392 |
| Between 9 and 15 months | .437 | .564 |
| Between 15 and 21 months | .437 | .437 |

The actual average daily gains by our steers, as shown in Table 52, for the periods for which the protein and energy content of the rations are computed in Table 51, are shown also in Table 63, which likewise includes what was called on page 22 the virtual age of the animals, that is, the age exclusive of the respiration calorimeter experiments.

TABLE 63.—*Average daily gains in live weight.*

| Periods. | Steer A. | | Steer B. | |
|---|---|---|---|---|
| | Virtual age. | Average daily gain. | Virtual age. | Average daily gain. |
| | *Months.* | *Kilos.* | *Months.* | *Kilos.* |
| Oct. 1 to Dec. 10, 1904 | 8.5–10.9 | 0.482 | 10.9–13.2 | 0.620 |
| Apr. 2 to July 15, 1905 | 10.9–14.4 | .359 | | |
| May 2 to July 15, 1905 | | | 13.2–15.4 | .559 |
| Oct. 6 to Dec. 3, 1905 | 17.0–19.0 | .448 | 18.1–20.2 | .546 |
| Apr. 8 to July 6, 1906 | 19.0–22.0 | .594 | | |
| Apr. 15 to July 6, 1906 | | | 20.2–23.1 | .429 |
| Oct. 26 to Dec. 15, 1906 | 25.0–26.2 | .726 | 26.2–27.5 | .410 |

On the average of the foregoing feeding periods, aggregating 17.7 months for steer A and 16.6 months for steer B, the average daily gains per head were, respectively, 0.426 kilogram and 0.422 kilogram, equivalent to an average of about 0.935 pound. The figures show clearly that the rate of gain during the feeding periods, outside of the respiration calorimeter experiments on limited rations, was fully as great as that predicated by Kellner for similar animals and would be very satisfactory in practice for animals not being fattened.

The rations shown in Table 51, computed to 1,000 kilograms live weight in direct proportion to the latter, are as follows:

TABLE 64.—*Average rations per 1,000 kilograms live weight.*

| Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|
| Virtual age in months. | Digestible protein. | Energy values. | Virtual age in months. | Digestible protein. | Energy values. |
| | *Kilos.* | *Therms.* | | *Kilos.* | *Therms.* |
| 8.5 to 10.9 | 1.42 | 23.05 | 10.9 to 13.2 | 1.64 | 27.43 |
| 10.9 to 14.4 | 1.40 | 22.22 | 13.2 to 15.6 | 1.77 | 31.18 |
| 17.0 to 19.0 | 1.09 | 18.98 | 18.1 to 20.2 | 1.25 | 22.58 |
| 19.0 to 22.0 | 1.03 | 22.20 | 20.2 to 23.1 | 1.23 | 23.57 |
| 25.0 to 26.2 | 0.72 | 17.18 | 26.2 to 27.5 | 0.85 | 20.35 |

### ENERGY VALUES.

The rations of steer B contained in the earlier periods of the experiments somewhat less energy value than the standards for dairy breeds call for and a somewhat larger amount during the later periods. The differences, however, are not very marked. Steer A, as already noted, consumed relatively less feed than steer B and consequently the energy value of his rations is notably less in the earlier periods than that called for by the standards for beef breeds and somewhat less in the later periods. On these rations both steers made on the whole quite similar gains per head, which, as already noted, were entirely satisfactory from a practical standpoint. Steer B being the lighter animal, his gains were relatively greater, although, as has already been shown, this greater relative gain seems to have had a lower energy value per unit. Steer A, on the other hand, seems to have had a relatively low maintenance requirement and possibly the average beef animal would require more feed for this purpose than did steer A. On the whole, the results upon these two animals indicate that for simple growth without material fattening, Kellner's standards as regards energy might be somewhat reduced.

### PROTEIN SUPPLY.

As regards the protein supply, we find a striking contrast between our rations and the accepted standards. Our two steers made entirely satisfactory gains on rations whose digestible protein ranged in the case of steer B from 70 to 95 per cent of the formulated requirements of the dairy breeds, and in the case of steer A from 50 to 70 per cent of those of the beef breeds. The difference is greatest at the earliest ages and gradually diminishes. One of us[1] has previously called attention to the fact that the protein supply called for by the current feeding standards for growing cattle is greatly in excess of the sum of the maintenance requirement and the amount actually stored up in the body, and that we have no recorded determinations of the minimum protein demands of such animals. The quantities of digestible protein consumed by the two steers in this investigation, although less than those called for by the standards, were still considerably in excess of the amounts calculated in the publication referred to, but, on the other hand, our results afford no proof that the minimum was reached. Of course it must be regarded as probable that some waste of nitrogenous matter would be involved in the chemical reconstitution necessary in changing food protein to body protein, while it is not impossible that a certain surplus of protein may be necessary for, or at least favorable to, growth. The tendency of recent investigations, however, is to show that in all branches of feeding the minimum protein requirement has been considerably exaggerated. This has been shown to be true of the maintenance requirement and of the requirement for milk production, while our results suggest that it is also true for growth. At any rate this branch of the subject seems worthy of further investigation.

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[1] Armsby: Bureau of Animal Industry, Bulletin 108, pp. 27-29 and pp. 57-65.

# PART II. DETAILS OF RESPIRATION CALORIMETER EXPERIMENTS AND OF DIGESTION AND METABOLISM TRIALS.

In the following pages are recorded the details of the respiration-calorimeter experiments of 1905, 1906, and 1907, whose general plan has been stated on pages 23–25, and whose results have been discussed in Part I, and likewise the particulars of the digestion and metabolism trials made during the intermediate feeding periods as described in Part I, pages 66–77, in connection with the discussion of the protein and energy content of the rations consumed.

## RESPIRATION CALORIMETER EXPERIMENTS OF 1905.

### FEEDING STUFFS.

*Hay.*—The hay used was nearly pure timothy hay grown upon the experiment station farm. It contained a slight admixture of red clover, but was the purest available. It was cut during the last week in June, 1904, was housed in good condition, and when taken from the mow was very bright and showed no effects of one slight rain to which it was exposed during curing. Two tons of this hay were cut to 4 to 5 centimeter lengths on November 26, 1904. On November 29 the cut hay, which in the meantime had lain on the barn floor protected from the weather, was thoroughly mixed, and two general samples drawn for determination of the composition of the dry matter. The hay was stored in the loft of the barn, protected from the weather, and as portions were weighed out for the successive periods samples were taken for analysis. Table 65 shows the composition of the two general samples and of the seven samples taken during the progress of the experiments. The good general agreement of these nine analyses shows that a reasonably uniform material was used throughout the experiment.

TABLE 65.—*Composition of dry matter of timothy hay, 1905.*

| Components. | General samples. | | | Samples taken during experiments. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C. | D. | Average. | Period 1, both steers. | Period 1, steer A only. | Period 2, steer A, and Period 3, steer B. | Period 2, steer B. | Period 3, steer A. | Period 4, steer A. | Period 4, steer B. |
| | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* | *Per ct.* |
| Ash | 4.78 | 4.96 | 4.87 | 4.13 | 4.30 | 4.25 | 4.60 | 4.07 | 4.26 | 4.05 |
| Protein [1] | 4.74 | 5.41 | 5.08 | 4.56 | 5.21 | 4.96 | 6.06 | 5.09 | 4.26 | 4.26 |
| Nonprotein [1] | .59 | .18 | .39 | .78 | .40 | .52 | .07 | .77 | .71 | 1.11 |
| Crude fiber | 37.72 | 38.57 | 38.14 | 38.23 | 37.61 | 39.35 | 38.16 | 39.94 | 40.17 | 39.20 |
| Nitrogen-free extract | 50.12 | 48.91 | 49.51 | 50.32 | 50.41 | 49.08 | 49.42 | 48.39 | 48.75 | 49.40 |
| Ether extract | 2.05 | 1.97 | 2.01 | 1.98 | 2.07 | 1.84 | 1.69 | 1.74 | 1.85 | 1.98 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Total nitrogen | .884 | .904 | .894 | .896 | .919 | .904 | .985 | .977 | .831 | .918 |
| Protein nitrogen | .759 | .865 | .812 | .730 | .834 | .793 | .970 | .814 | .681 | .682 |
| Carbon | 46.795 | 46.902 | 46.849 | 47.394 | 47.482 | 47.039 | 47.282 | 47.272 | 46.985 | 46.967 |
| Hydrogen | 6.521 | 6.083 | 6.302 | 6.032 | 6.012 | 6.033 | 7.340 | 6.331 | 6.031 | 5.679 |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Energy (calories per gram) | 4.4399 | 4.4218 | 4.4309 | 4.4909 | 4.4957 | 4.4084 | 4.4826 | 4.5015 | 4.4882 | 4.4828 |

[1] Computed from nitrogen, using the factors stated in Part III, page 203.

*Wheat bran.*—Fresh bran purchased directly from the mill was used. About 500 kilograms were thoroughly mixed and two general samples taken for determination of the composition of the dry matter. The remainder was stored, protected from moisture and vermin, and further samples were taken as the bran was weighed out for the several periods in which it was used. The results of all the analyses are contained in the table below and indicate a satisfactory degree of uniformity in the bran, as was the case with the hay.

TABLE 66.—*Composition of dry matter of wheat bran, 1905.*

| Components. | General samples. | | | Samples taken during experiments. | | | |
|---|---|---|---|---|---|---|---|
| | E. | F. | Average. | Period 1, both steers. | Period 1, steer A only. | Period 2, steer A. | Period 2, steer B. |
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Ash | 7.38 | 7.66 | 7.52 | 7.33 | 7.55 | 7.54 | 7.45 |
| Protein [1] | 14.49 | 14.51 | 14.50 | 15.27 | 14.31 | 14.74 | 13.90 |
| Nonprotein [1] | .66 | .32 | .49 | .50 | .88 | .85 | 1.11 |
| Crude fiber | 11.48 | 11.51 | 11.49 | 10.79 | 10.64 | 11.29 | 10.44 |
| Nitrogen-free extract | 61.84 | 61.92 | 61.88 | 61.30 | 61.95 | 61.31 | 62.15 |
| Ether extract | 4.15 | 4.08 | 4.12 | 4.81 | 4.67 | 4.27 | 4.95 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Total nitrogen | 2.683 | 2.613 | 2.648 | 2.784 | 2.698 | 2.767 | 2.674 |
| Protein nitrogen | 2.542 | 2.545 | 2.544 | 2.678 | 2.510 | 2.586 | 2.438 |
| Carbon | 46.781 | 46.003 | 46.392 | 45.979 | 45.623 | 45.740 | 44.379 |
| Hydrogen | 6.628 | 6.907 | 6.768 | 6.141 | 6.581 | 6.392 | 7.150 |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Energy (calories per gram) | 4.5340 | 4.5295 | 4.5318 | 4.5651 | 4.5238 | 4.5584 | 4.4608 |

[1] Computed from nitrogen, using the factors stated in Part III, page 203.

### PERIODS AND RATIONS.

Beginning on December 10, 1904, the feed of the animals was changed to timothy hay and wheat bran and the ration brought gradually to that assigned to the first period. The several periods and rations were as shown in tables 67 and 68, the dates being inclusive in all cases. Throughout this investigation the term "day" signifies the 24 hours ending upon the date named.

It was found necessary, as appears from Table 67, to postpone Period II for steer B until the very close of the experiments. The same number, however, was retained for this period so as to facilitate comparisons between the different periods and animals.

The ration fed during the transition feeding differed only in amount and not in kind of feeding stuffs from that of the periods proper. As a matter of convenience in connection with the calorimeter experiments, the hour of 6 p. m. was taken as the beginning and ending of tho day. Approximately one-half of the feed was given at 6 p. m. and the remainder 12 hours later. The weight of the animal was taken daily at 1 p. m., 24 hours after the last watering. The rectal temperature was then taken and the animal was watered and reweighed, the difference between the two weighings representing the amount of water consumed. On the days when the animal was in the calorimeter the live weight was taken immediately before entering and immediately after leaving the apparatus and the animal was watered immediately after the morning feeding at 6 a. m.

TABLE 67.—*Periods, 1905.*

| Periods. | Steer A. | | Steer B. | |
|---|---|---|---|---|
| | Preliminary feeding. | Excreta collected. | Preliminary feeding. | Excreta collected. |
| I | Dec. 16, 1904, to Jan. 4, 1905. | Jan. 5 to 22, 1905 | Dec. 16, 1904, to Jan. 18, 1905. | Jan. 19 to 28, 1905. |
| Transition feeding. | Jan. 23 to 28, 1905 | | Mar. 26 to Apr. 1, 1905. | |
| II | Jan. 29 to Feb. 8, 1905. | Feb. 9 to 18, 1905 | Apr. 2 to 26, 1905 | Apr. 27 to May 6, 1905. |
| Transition feeding. | | | Jan. 29 to Feb. 4, 1905. | |
| III | Feb. 19 to Mar. 1, 1905. | Mar. 2 to 11, 1905 | Feb. 5 to 15, 1905 | Feb. 16 to 25, 1905. |
| Transition feeding. | Mar. 12 to 18, 1905 | | Feb. 26 to 28, 1905 | |
| IV | Mar. 19 to 22, 1905 | Mar. 23 to Apr. 1, 1905. | Feb. 29 to Mar. 15, 1905. | Mar. 16 to 25, 1905. |

TABLE 68.—*Daily rations, 1905.*

| Periods. | Steer A. | | Steer B. | |
|---|---|---|---|---|
| | Timothy hay. | Wheat bran. | Timothy hay. | Wheat bran. |
| | *Kilos.* | *Kilos.* | *Kilos.* | *Kilos.* |
| I | 2.25 | 1.60 | 2.00 | 1.20 |
| II | 2.25 | 2.00 | 2.00 | 2.00 |
| III | 2.25 | | 2.00 | |
| IV | 4.00 | | 3.00 | |

## DIGESTIBILITY OF TOTAL RATIONS.

A uniform aliquot sample of the fresh feces was set aside daily and preserved in a cold place with the addition of a small amount of carbon bisulphid. At the close of the period the total nitrogen was determined in the mixed fresh feces and the other ingredients in an air-dried sample. The daily weights of the excreta, together with the live weights of the animals, weight of water consumed, and the composition of the dry matter of the feces and of the feed refused are recorded in Tables IV, V, and VI of the appendix. From the data there recorded the digestibility of the several rations is computed in the following tables.

In Period I the feed was not readily eaten by steer B and salt was used to render it more palatable. In the computations of digestibility the uneaten residues in this period have been corrected for the salt which they contained on the basis of a determination of soluble chlorin. A smaller but similar correction is also made in Period IV with the same animal.

TABLE 69.—*Feed and excreta—Period I, 1905.*

| Feed and feces. | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of days. | Fresh weight. | Dry matter. | | Number of days. | Fresh weight. | Dry matter. | |
| Timothy hay: | | *Grams.* | *Per cent.* | *Grams.* | | *Grams.* | *Per cent.* | *Grams.* |
| Total | 18 | 40,500.0 | 87.91 | 35,602.2 | 10 | 20,000.0 | 88.50 | 17,699.8 |
| Offered per day | | 2,250.0 | | 1,977.8 | | 2,000.0 | | 1,770.0 |
| Wheat bran: | | | | | | | | |
| Total | 18 | 28,800.0 | 85.64 | 24,664.2 | 10 | 12,000.0 | 86.04 | 10,324.8 |
| Offered per day | | 1,600.0 | | 1,370.2 | | 1,200.0 | | 1,032.5 |
| Uneaten residues: | | | | | | | | |
| Jan. 24 | | | | | | 623.0 | 80.15 | 499.3 |
| Jan. 26 | | | | | | 423.0 | 89.76 | 379.8 |
| Jan. 25 and 26 | | | | | | 45.2 | 90.05 | 40.7 |
| Total | | | | | 10 | 1,091.2 | | 919.8 |
| Uneaten per day | | | | | | 109.1 | | 92.0 |
| Feces: | | | | | | | | |
| Collected | 18 | 135,460.0 | 18.75 | 25,394.7 | 10 | 55,265.0 | 20.17 | 11,146.9 |
| Spilled Jan. 19 | | 25.0 | | 12.7 | | | | |
| Spilled Jan. 23 | | 9.2 | | 2.2 | | | | |
| Spilled Jan. 26 | | | | | | 66.7 | 44.84 | 29.9 |
| In duct Jan. 19 | | 48.2 | | 45.8 | | | | |
| In duct Jan. 27 | | | | | | 42.0 | 94.71 | 39.8 |
| In duct Jan. 28 | | | | | | 16.2 | | 4.1 |
| Total | | 135,542.0 | | 25,455.4 | | 55,389.9 | | 11,220.7 |
| Excreted per day | | 7,530.0 | | 1,414.2 | | 5,539.0 | | 1,122.1 |

### TABLE 70.—*Digestibility of rations—Period I, 1905.*

| Feed and feces. | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Carbon. | Hydrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Steer A.*** | *Grams.* | *Gms.* | *Grams.* | *Gms.* | *Grams.* | *Gms.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Gms.* | *Calories.* |
| Timothy hay[1] | 1,977.8 | 83.5 | 1,894.3 | 96.5 | 11.6 | 749.9 | 996.5 | 39.8 | 18.0 | 938.2 | 119.1 | 8,886.8 |
| Wheat bran | 1,370.2 | 101.9 | 1,268.3 | 202.7 | 9.5 | 146.9 | 844.3 | 64.9 | 37.5 | 627.5 | 87.2 | 6,226.6 |
| Total | 3,348.0 | 185.4 | 3,162.6 | 299.2 | 21.1 | 896.8 | 1,840.8 | 104.7 | 55.5 | 1,565.7 | 206.3 | 15,113.4 |
| Feces | 1,414.2 | 109.9 | 1,304.3 | 139.0 | ........ | 501.5 | 636.9 | 26.9 | 22.2 | 666.1 | 77.4 | 6,525.3 |
| Digested | 1,933.8 | 75.5 | 1,858.3 | 160.2 | 21.1 | 395.3 | 1,203.9 | 77.8 | 33.3 | 899.6 | 128.9 | 8,588.1 |
| Percentage digestibility | 57.76 | 40.74 | 58.75 | 53.54 | [100.00] | 44.08 | 65.40 | 74.30 | 60.00 | 57.46 | 62.48 | 56.83 |
| ***Steer B.*** | | | | | | | | | | | | |
| Timothy hay | 1,770.0 | 73.1 | 1,696.9 | 80.7 | 13.8 | 676.7 | 890.7 | 35.0 | 15.9 | 838.9 | 106.8 | 7,948.9 |
| Wheat bran | 1,032.5 | 75.7 | 956.8 | 157.7 | 5.1 | 111.4 | 632.9 | 49.7 | 28.7 | 474.7 | 63.4 | 4,713.5 |
| Total | 2,802.5 | 148.8 | 2,653.7 | 238.4 | 18.9 | 788.1 | 1,523.6 | 84.7 | 44.6 | 1,313.6 | 170.2 | 12,662.4 |
| Uneaten: | | | | | | | | | | | | |
| Jan. 24 | [2] 49.9 | 4.9 | 45.0 | 6.8 | .8 | 7.7 | 27.8 | 1.9 | 1.3 | 22.2 | 3.4 | 214.8 |
| Jan. 26 | 38.0 | 2.8 | 35.2 | 4.6 | .2 | 8.1 | 21.0 | 1.3 | .8 | 17.4 | 1.8 | 170.7 |
| Jan. 25, 26 | 4.1 | .4 | 3.7 | .6 | .0 | .7 | 2.2 | .2 | .1 | 1.9 | .3 | 18.3 |
| Total | 92.0 | 8.1 | 83.9 | 12.0 | 1.0 | 16.5 | 51.0 | 3.4 | 2.2 | 41.5 | 5.5 | 403.8 |
| Eaten | 2,710.5 | 140.7 | 2,569.8 | 226.4 | 17.9 | 771.6 | 1,472.6 | 81.3 | 42.4 | 1,272.1 | 164.7 | 12,258.6 |
| Feces | 1,122.1 | 98.4 | 1,023.7 | 108.9 | ........ | 394.4 | 489.9 | 30.5 | 17.4 | 530.3 | 63.5 | 5,252.6 |
| Digested | 1,588.4 | 42.3 | 1,546.1 | 117.5 | 17.9 | 377.2 | 982.7 | 50.8 | 25.0 | 741.8 | 101.2 | 7,006.0 |
| Percentage digestibility | 58.60 | 30.06 | 60.16 | 51.90 | 100.0 | 48.89 | 66.73 | 62.48 | 58.96 | 58.31 | 61.45 | 57.15 |

[1] The average composition of the two samples taken for steer A is used in computing the digestibility.
[2] Exclusive of 6.8 grams of salt.

### TABLE 71.—*Feed and excreta—Period II, 1905.*

| Feed and feces. | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of days. | Fresh weight. | Dry matter. | | Number of days. | Fresh weight. | Dry matter. | |
| Timothy hay: | | *Grams.* | *Per cent.* | *Grams.* | | *Grams.* | *Per cent.* | *Grams.* |
| Total | 10 | 22,500.0 | 88.69 | 19,955.7 | 10 | 20,000.0 | 88.95 | 17,790.0 |
| Offered per day | ........ | 2,250.0 | .......... | 1,995.6 | ........ | 2,000.0 | .......... | 1,779.0 |
| Wheat bran: | | | | | | | | |
| Total | 10 | 30,000.0 | 86.11 | 25,832.7 | 10 | 20,000.0 | 90.13 | 18,026.0 |
| Offered per day | ........ | 3,000.0 | .......... | 2,583.2 | ........ | 2,000.0 | .......... | 1,802.6 |
| Feces: | | | | | | | | |
| Collected | 10 | 94,840.0 | 18.49 | 17,538.8 | 10 | 68,600.0 | 19.96 | 13,689.2 |
| Spilled Feb. 17 | ........ | 629.4 | 27.02 | 170.1 | ........ | .......... | .......... | .......... |
| Spilled May 5 | ........ | .......... | .......... | .......... | ........ | 54.6 | 45.24 | 24.7 |
| In duct Feb. 16 | ........ | 370.2 | 23.37 | 91.0 | ........ | .......... | .......... | .......... |
| In duct Feb. 18 | ........ | 378.3 | 25.44 | 96.3 | ........ | .......... | .......... | .......... |
| In duct May 4 | ........ | .......... | .......... | .......... | ........ | 179.5 | 20.62 | 37.0 |
| In duct May 6 | ........ | .......... | .......... | .......... | ........ | 42.0 | 25.48 | 10.7 |
| Total | ........ | 96,217.9 | .......... | 17,896.2 | ........ | 68,876.1 | .......... | 13,761.6 |
| Excreted per day | ........ | 9,621.8 | .......... | 1,789.6 | ........ | 6,887.6 | .......... | 1,376.2 |

TABLE 72.—*Digestibility of rations—Period II, 1905.*

| | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Carbon. | Hydrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Steer A.*** | *Grams.* | *Gms.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Gms.* | *Calories.* |
| Timothy hay | 1,995.6 | 84.8 | 1,910.8 | 99.0 | 10.4 | 785.3 | 979.4 | 36.7 | 18.0 | 938.7 | 120.4 | 8,797.4 |
| Wheat bran | 2,583.2 | 194.8 | 2,388.4 | 380.8 | 21.9 | 291.6 | 1,583.8 | 110.3 | 71.5 | 1,181.6 | 165.1 | 11,775.3 |
| | 4,578.8 | 279.6 | 4,299.2 | 479.8 | 32.3 | 1,076.9 | 2,563.2 | 147.0 | 89.5 | 2,120.3 | 285.5 | 20,572.7 |
| Feces | 1,789.6 | 144.2 | 1,645.4 | 186.7 | ..... | 601.3 | 816.2 | 41.2 | 29.9 | 844.0 | 104.4 | 8,261.0 |
| Digested | 2,789.2 | 135.4 | 2,653.8 | 293.1 | 32.3 | 475.6 | 1,747.0 | 105.8 | 59.6 | 1,276.3 | 181.1 | 12,311.7 |
| Percentage digestibility | 60.91 | 48.43 | 61.73 | 61.09 | 100.0 | 44.16 | 68.16 | 71.97 | 66.59 | 60.19 | 63.43 | 59.84 |
| ***Steer B.*** | | | | | | | | | | | | |
| Timothy hay | 1,779.0 | 81.8 | 1,697.2 | 107.8 | 1.2 | 678.9 | 879.2 | 30.1 | 17.5 | 841.1 | 130.6 | 7,974.5 |
| Wheat bran | 1,802.6 | 134.3 | 1,668.3 | 250.6 | 20.0 | 188.2 | 1,120.3 | 89.2 | 48.2 | 800.0 | 128.9 | 8,041.0 |
| | 3,581.6 | 216.1 | 3,365.5 | 358.4 | 21.2 | 867.1 | 1,999.5 | 119.3 | 65.7 | 1,641.1 | 259.5 | 16,015.5 |
| Feces | 1,376.2 | 130.0 | 1,246.2 | 140.1 | ..... | 468.6 | 602.1 | 35.4 | 22.4 | 636.0 | 92.9 | 6,297.9 |
| Digested | 2,205.4 | 86.1 | 2,119.3 | 218.3 | 21.2 | 398.5 | 1,397.4 | 83.9 | 43.3 | 1,005.1 | 166.6 | 9,717.6 |
| Percentage digestibility | 61.57 | 39.84 | 62.97 | 60.91 | 100.0 | 45.96 | 69.89 | 70.33 | 65.91 | 61.25 | 64.20 | 60.68 |

TABLE 73.—*Feed and excreta—Period III, 1905.*

| Feed and feces. | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of days. | Fresh weight. | Dry matter. | | Number of days. | Fresh weight. | Dry matter. | |
| | | *Grams.* | *Per cent.* | *Grams.* | | *Grams.* | *Per cent.* | *Grams.* |
| Timothy hay: | | | | | | | | |
| Total | 10 | 22,500.0 | 88.93 | 20,009.9 | 10 | 20,000.0 | 88.69 | 17,738.4 |
| Offered per day | | 2,250.0 | | 2,001.0 | | 2,000.0 | | 1,773.8 |
| Feces: | | | | | | | | |
| Collected | 10 | 44,406.0 | 20.35 | 9,035.5 | 10 | 36,550.0 | 21.88 | 7,996.7 |
| Spilled, Feb. 22 | | | | | | 1.4 | 92.86 | 1.3 |
| Spilled, Mar. 10 | | 25.2 | 63.24 | 15.9 | | | | |
| In duct, Feb. 23 | | | | | | 10.8 | 33.33 | 3.6 |
| In duct, Feb. 25 | | | | | | 21.4 | 27.11 | 5.8 |
| In duct, Mar. 9 | | 158.5 | 23.60 | 37.4 | | | | |
| In duct, Mar. 11 | | 9.0 | 37.36 | 3.3 | | | | |
| Total | | 44,597.7 | | 9,092.1 | | 36,583.6 | | 8,007.4 |
| Excreted per day | | 4,459.8 | | 909.2 | | 3,658.4 | | 800.7 |

TABLE 74.—*Digestibility of rations—Period III, 1905.*

| | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Carbon. | Hydrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Steer A.*** | *Grams.* | *Gms.* | *Grams.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Cals.* |
| Timothy hay | 2,001.0 | 81.4 | 1,919.6 | 101.9 | 15.4 | 799.2 | 968.3 | 34.8 | 19.5 | 945.9 | 126.7 | 9,007.5 |
| Feces | 909.2 | 51.6 | 857.6 | 78.3 | ...... | 363.1 | 396.9 | 19.3 | 12.5 | 459.7 | 52.5 | 4,419.3 |
| Digested | 1,091.8 | 29.8 | 1,062.0 | 23.6 | 15.4 | 436.1 | 571.4 | 15.5 | 7.0 | 486.2 | 74.2 | 4,588.2 |
| Percentage digestibility | 54.56 | 36.61 | 55.32 | 23.16 | 100.00 | 54.57 | 59.01 | 44.54 | 36.22 | 51.40 | 58.56 | 50.94 |
| ***Steer B.*** | | | | | | | | | | | | |
| Timothy hay | 1,773.8 | 75.4 | 1,698.4 | 88.0 | 9.2 | 698.0 | 870.6 | 32.6 | 16.0 | 834.4 | 107.0 | 7,819.6 |
| Feces | 800.7 | 47.0 | 753.7 | 79.1 | ...... | 308.4 | 348.7 | 17.5 | 12.7 | 401.1 | 47.2 | 3,918.9 |
| Digested | 973.1 | 28.4 | 944.7 | 8.9 | 9.2 | 389.6 | 521.9 | 15.1 | 3.3 | 433.3 | 59.8 | 3,900.7 |
| Percentage digestibility | 54.86 | 37.67 | 55.62 | 10.11 | 100.00 | 55.82 | 59.95 | 46.32 | 20.63 | 51.93 | 55.89 | 49.88 |

TABLE 75.—*Feed and excreta—Period IV, 1905.*

| Feed and feces. | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of days. | Fresh weight. | Dry matter. | | Number of days. | Fresh weight. | Dry matter. | |
| **Timothy hay:** | | *Grams.* | *Per cent.* | *Grams.* | | *Grams.* | *Per cent.* | *Grams.* |
| Total | 10 | 40.000.0 | 87.33 | 34,931.2 | 10 | 30.000.0 | 88.58 | 26,573.7 |
| Offered per day | | 4,000.0 | | 3,493.1 | | 3,000.0 | | 2,657.4 |
| **Uneaten residues:** | | | | | | | | |
| March 24 | | | | | | 481.0 | 93.25 | 448.6 |
| March 24 | | | | | | 13.0 | 93.07 | 12.1 |
| March 25 | | | | | | 35.9 | 91.09 | 32.7 |
| Total | | | | | | 529.9 | | 493.4 |
| Uneaten per day | | | | | | 53.0 | | [1] 49.3 |
| **Feces:** | | | | | | | | |
| Collected | 10 | 97,480.0 | 17.21 | 16,779.2 | 10 | 58,196.0 | 20.16 | 11,730.9 |
| Spilled, Mar. 24 | | | | | | 12.0 | 59.16 | 7.1 |
| Spilled, Mar. 31 | | 5.0 | 84.00 | 4.2 | | | | |
| In duct, Mar. 23 | | | | | | 5.8 | 82.76 | 4.8 |
| In duct, Mar. 25 | | | | | | 4.8 | 56.25 | 2.7 |
| In duct, Mar. 30 | | 54.0 | 37.27 | 20.1 | | | | |
| In duct, Apr. 1 | | 24.0 | 52.93 | 12.7 | | | | |
| Total | | 97,563.0 | | 16,816.2 | | 58,217.6 | | 11,745.5 |
| Excreted per day | | 9,756.3 | | 1,681.6 | | 5,821.8 | | 1,174.6 |

[1] Including salt. Without salt it is 47.8.

TABLE 76.—*Digestibility of rations—Period IV, 1905.*

| | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Carbon. | Hydrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Steer A.*** | *Grams.* | *Gms.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Gms.* | *Calories.* |
| Timothy hay | 3,493.1 | 148.8 | 3,344.3 | 148.8 | 24.8 | 1,403.2 | 1,702.9 | 64.6 | 29.0 | 1,641.2 | 210.7 | 15,677.7 |
| Feces | 1,681.6 | 94.7 | 1,586.9 | 136.2 | ...... | 690.8 | 724.4 | 35.5 | 21.8 | 835.3 | 115.4 | 8,055.9 |
| Digested | 1,811.5 | 54.1 | 1,757.4 | 12.6 | 24.8 | 712.4 | 978.5 | 29.1 | 7.2 | 805.9 | 95.3 | 7,621.8 |
| Percentage digestibility | 51.86 | 36.36 | 52.55 | 8.47 | 100.00 | 50.77 | 57.46 | 45.05 | 24.83 | 49.10 | 45.23 | 48.62 |
| ***Steer B.*** | | | | | | | | | | | | |
| Timothy hay | 2,657.4 | 107.6 | 2,549.8 | 113.2 | 29.5 | 1,041.7 | 1,312.8 | 52.6 | 24.4 | 1,248.1 | 150.9 | 11,912.6 |
| Uneaten | [1] 47.8 | 2.0 | 45.8 | 3.6 | 0.1 | 17.3 | 23.6 | 1.2 | 0.6 | 23.2 | ...... | 219.6 |
| | 2,609.6 | 105.6 | 2,504.0 | 109.6 | 29.4 | 1,024.4 | 1,289.2 | 51.4 | 23.8 | 1,224.9 | 150.9 | 11,693.0 |
| Feces | 1,174.6 | 76.3 | 1,098.3 | 112.5 | ...... | 464.6 | 497.1 | 24.1 | 18.0 | 584.2 | 67.0 | 5,676.8 |
| Digested | 1,435.0 | 29.3 | 1,405.7 | −2.9 | 29.4 | 559.8 | 792.1 | 27.3 | 5.8 | 640.7 | 83.9 | 6,016.2 |
| Percentage digestibility | 54.99 | 27.75 | 56.14 | ...... | 100.00 | 54.65 | 61.44 | 53.11 | 24.33 | 52.31 | 55.60 | 51.45 |

[1] Exclusive of salt.

## DIGESTIBILITY OF TIMOTHY HAY AND OF WHEAT BRAN.

From the data contained in the foregoing tables the percentage digestibility of the several ingredients of the wheat bran may also be computed upon the customary assumption that the latter did not affect the digestibility of the hay. In making this computation the average digestibility of the hay in Periods III and IV has been used, the average being computed as shown in the table below, giving weight to each period in proportion to the amount of hay consumed.

TABLE 77.—*Average digestibility of timothy hay, 1905.*

| | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Carbon. | Hydrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Steer A.* | | | | | | | | | | | | |
| Fed in Period III | *Gms.*<br>2,001.0 | *Gms.*<br>81.4 | *Gms.*<br>1,919.6 | *Gms.*<br>101.9 | *Gms.*<br>15.4 | *Gms.*<br>799.2 | *Gms.*<br>968.3 | *Gms.*<br>34.8 | *Gms.*<br>19.5 | *Gms.*<br>945.9 | *Gms.*<br>126.7 | *Calories.*<br>9,007.5 |
| Fed in Period IV | 3,493.1 | 148.8 | 3,344.3 | 148.8 | 24.8 | 1,403.2 | 1,702.9 | 64.6 | 29.0 | 1,641.2 | 210.7 | 15,677.7 |
| Total | 5,494.1 | 230.2 | 5,263.9 | 250.7 | 40.2 | 2,202.4 | 2,671.2 | 99.4 | 48.5 | 2,587.1 | 337.4 | 24,685.2 |
| Digested in period III | 1,091.8 | 29.8 | 1,062.0 | 23.6 | 15.4 | 436.1 | 571.4 | 15.5 | 7.0 | 486.2 | 74.2 | 4,588.2 |
| Digested in Period IV | 1,811.5 | 54.1 | 1,757.4 | 12.6 | 24.8 | 712.4 | 978.5 | 29.1 | 7.2 | 805.9 | 95.3 | 7,621.8 |
| Total | 2,903.3 | 83.9 | 2,819.4 | 36.2 | 40.2 | 1,148.5 | 1,549.9 | 44.6 | 14.2 | 1,292.1 | 169.5 | 12,210.0 |
| Percentage digestibility | 52.84 | 36.45 | 53.56 | 14.44 | 100.0 | 52.15 | 58.02 | 44.87 | 29.28 | 49.94 | 50.24 | 49.46 |
| *Steer B.* | | | | | | | | | | | | |
| Fed in Period III | 1,773.8 | 75.4 | 1,698.4 | 88.0 | 9.2 | 698.0 | 870.6 | 32.6 | 16.0 | 834.4 | 107.0 | 7,819.6 |
| Fed in Period IV | 2,609.6 | 105.6 | 2,504.0 | 109.6 | 29.4 | 1,024.4 | 1,289.2 | 51.4 | 23.8 | 1,224.9 | 150.9 | 11,693.0 |
| Total | 4,383.4 | 181.0 | 4,202.4 | 197.6 | 38.6 | 1,722.4 | 2,159.8 | 84.0 | 39.8 | 2,059.3 | 257.9 | 19,512.6 |
| Digested in Period III | 973.1 | 28.4 | 944.7 | 8.9 | 9.2 | 389.6 | 521.9 | 15.1 | 3.3 | 433.3 | 59.8 | 3,900.7 |
| Digested in Period IV | 1,435.0 | 29.3 | 1,405.7 | −2.9 | 29.4 | 559.8 | 792.1 | 27.3 | 5.8 | 640.7 | 83.9 | 6,016.2 |
| Total | 2,408.1 | 57.7 | 2,350.4 | 6.0 | 38.6 | 949.4 | 1,314.0 | 42.4 | 9.1 | 1,074.0 | 143.7 | 9,916.9 |
| Percentage digestibility | 54.94 | 31.88 | 55.93 | 3.04 | 100.0 | 55.12 | 60.84 | 50.48 | 22.86 | 52.15 | 55.72 | 50.82 |

In the following computation of the digestibility of the wheat bran it has been assumed that the uneaten residue left by steer B in Period I contained hay and bran in the same proportion as the ration weighed out.

TABLE 78.—*Computed digestibility of wheat bran, 1906.*

| | Dry matter. | Ash. | Organic matter | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Carbon. | Hydrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Steer A.* | | | | | | | | | | | | |
| Period I: | | | | | | | | | | | | |
| Total digested..... | *Gms.*<br>1,933.8 | *Gms.*<br>75.5 | *Gms.*<br>1,858.3 | *Gms.*<br>160.2 | *Gms.*<br>21.1 | *Gms.*<br>395.3 | *Gms.*<br>1,203.9 | *Gms.*<br>77.8 | *Gms.*<br>33.3 | *Gms.*<br>899.6 | *Gms.*<br>128.9 | *Calories.*<br>8,588.1 |
| Computed digestible hay...... | 1,045.1 | 30.4 | 1,014.6 | 13.9 | 11.6 | 391.1 | 578.2 | 17.9 | 5.3 | 468.5 | 59.8 | 4,395.5 |
| Digested from bran.... | 888.7 | 45.1 | 843.7 | 146.3 | 9.5 | 4.2 | 625.7 | 59.9 | 28.0 | 431.1 | 69.1 | 4,192.6 |
| Total in bran | 1,370.2 | 101.9 | 1,268.3 | 202.7 | 9.5 | 146.9 | 844.3 | 64.9 | 37.5 | 627.5 | 87.2 | 6,226.6 |
| Percentage digestibility..... | 64.86 | 44.26 | 66.52 | 72.18 | 100.00 | 2.86 | 74.11 | 92.30 | 74.67 | 68.70 | 79.24 | 67.33 |
| | | | | | | 63.55 | | | | | | |
| Period II: | | | | | | | | | | | | |
| Total digested... | 2,789.2 | 135.4 | 2,653.8 | 293.1 | 32.3 | 475.6 | 1,747.0 | 105.8 | 59.6 | 1,276.3 | 181.1 | 12,311.7 |
| Computed digestible hay....... | 1,054.5 | 30.9 | 1,023.4 | 14.3 | 10.4 | 409.5 | 568.2 | 16.5 | 5.3 | 468.8 | 60.5 | 4,351.2 |
| Digested from bran.... | 1,734.7 | 104.5 | 1,630.4 | 278.8 | 21.9 | 66.1 | 1,178.8 | 89.3 | 54.3 | 807.5 | 120.6 | 7,960.5 |
| Total in bran | 2,583.2 | 194.8 | 2,388.4 | 380.8 | 21.9 | 291.6 | 1,583.8 | 110.3 | 71.5 | 1,181.6 | 165.1 | 11,775.2 |
| Percentage digestibility..... | 67.15 | 53.64 | 68.26 | 73.21 | 100.00 | 22.67 | 74.43 | 80.96 | 75.94 | 68.34 | 73.05 | 67.60 |
| | | | | | | 66.38 | | | | | | |
| *Steer B.* | | | | | | | | | | | | |
| Period I: | | | | | | | | | | | | |
| Total digested..... | 1,588.4 | 42.3 | 1,546.1 | 117.5 | 17.9 | 377.2 | 982.7 | 50.8 | 25.0 | 741.8 | 101.2 | 7,006.0 |
| Computed digestible hay.... | 940.5 | 22.0 | 919.1 | 2.3 | 13.1 | 365.2 | 523.8 | 17.0 | 3.5 | 423.7 | 57.6 | 3,911.0 |
| Digested from bran.... | 647.9 | 20.3 | 627.0 | 115.2 | 4.8 | 12.0 | 458.9 | 33.8 | 21.5 | 318.1 | 43.6 | 3,095.0 |
| Total in bran | 998.6 | 71.6 | 926.6 | 149.8 | 4.8 | 109.1 | 611.7 | 47.7 | 27.3 | 459.7 | 61.4 | 4,563.2 |
| Percentage digestibility..... | 64.88 | 28.35 | 67.67 | 76.90 | 100.00 | 11.00 | 75.02 | 70.86 | 78.75 | 69.20 | 71.01 | 67.83 |
| | | | | | | 65.33 | | | | | | |
| Period II: | | | | | | | | | | | | |
| Total digested..... | 2,205.4 | 86.1 | 2,119.3 | 218.3 | 21.2 | 398.5 | 1,397.4 | 83.9 | 43.3 | 1,005.1 | 166.6 | 9,717.6 |
| Computed digestible hay.... | 977.4 | 26.1 | 949.2 | 3.3 | 1.2 | 374.2 | 534.9 | 15.2 | 4.0 | 438.6 | 72.8 | 4,052.6 |
| Digested from bran.... | 1,228.0 | 60.0 | 1,170.1 | 215.0 | 20.0 | 24.3 | 862.5 | 68.7 | 39.3 | 566.5 | 93.8 | 5,665.0 |
| Total in bran | 1,802.6 | 134.3 | 1,618.3 | 250.6 | 20.00 | 188.2 | 1,120.3 | 89.2 | 48.2 | 800.0 | 128.9 | 8,041.0 |
| Percentage digestibility..... | 68.12 | 44.68 | 70.14 | 85.79 | 100.00 | 12.91 | 76.99 | 77.02 | 81.54 | 70.81 | 72.77 | 70.45 |
| | | | | | | 67.77 | | | | | | |

## URINARY EXCRETION.

In a composite sample of the urine made up of aliquot daily samples, dry matter, total solids, nitrogen, carbon, organic hydrogen, and energy were determined. From the results of these determinations and the data for the weights of the urine contained in Table IV of the appendix, the total excretion has been computed as shown in Table 79. In case urine was spilled it was taken up with water, the total nitrogen determined in the mixed sample, including the water used to take it up, and it was assumed that the content of hydrogen, carbon, and energy was proportional to the nitrogen.

TABLE 79.—*Results on urine (inclusive of wash water), 1905.*

| | Weight. | Average specific gravity. | Total solids. | | Total nitrogen. | | Total carbon. | | Total hydrogen. | | Energy. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Per gram. | Total. |
| *Period I.* | | | | | | | | | | | | |
| **Steer A:** | *Gms.* | | *Per cent.* | *Gms.* | *Per cent.* | *Gms.* | *Per cent.* | *Gms.* | *Per cent.* | *Gms.* | *Calories.* | *Calories.* |
| Collected........ | 54,985.0 | 1.040 | 7.037 | 3,869.3 | 1.113 | 611.98 | 1.957 | 1,076.06 | 0.293 | 161.11 | 0.1997 | 10,980.5 |
| Spilled, Jan. 20.. | 358.7 | ...... | .150 | .5 | .024 | .08 | .042 | .15 | .006 | .02 | .0043 | 1.5 |
| Spilled, Jan. 21.. | 745.0 | ...... | 1.247 | 9.3 | .197 | 1.47 | .346 | 2.58 | .052 | .39 | .0353 | 26.3 |
| Spilled, Jan. 22.. | 550.4 | ...... | 2.216 | 12.2 | .351 | 1.98 | .617 | 3.40 | .092 | .51 | .0630 | 34.7 |
| Total........ | ...... | ...... | ...... | 3,891.3 | ...... | 615.46 | ...... | 1,082.19 | ...... | 162.03 | ...... | 11,043.0 |
| Average (18 days) | ...... | ...... | ...... | 216.2 | ...... | 34.2 | ...... | 60.1 | ...... | 9.0 | ...... | 613.5 |
| **Steer B:** | | | | | | | | | | | | |
| Collected........ | 20,675.0 | 1.044 | 7.957 | 1,645.1 | 1.274 | 263.40 | 2.159 | 446.37 | .319 | 65.95 | .2248 | 4,647.7 |
| Spilled, Jan. 26.. | 292.5 | ...... | 6.371 | 18.6 | 1.020 | 2.98 | 1.729 | 5.06 | .255 | .75 | .1800 | 52.7 |
| Total........ | ...... | ...... | ...... | 1,663.7 | ...... | 266.38 | ...... | 451.43 | ...... | 66.70 | ...... | 4,700.4 |
| Average (9 days) | ...... | ...... | ...... | 184.9 | ...... | 29.6 | ...... | 50.2 | ...... | 7.4 | ...... | 522.3 |
| *Period II.* | | | | | | | | | | | | |
| **Steer A:** | | | | | | | | | | | | |
| Collected........ | 32,310.0 | 1.035 | 7.684 | 2,482.7 | 1.209 | 390.63 | 1.742 | 562.84 | .267 | 86.27 | .1809 | 5,844.9 |
| Spilled, Feb. 18.. | 449.2 | ...... | .733 | 3.3 | .115 | .52 | .166 | .75 | .025 | .11 | .0172 | 7.7 |
| Spilled, Feb. 18.. | 110.5 | ...... | 8.861 | 9.8 | 1.395 | 1.54 | 2.010 | 2.22 | .308 | .34 | .2087 | 23.1 |
| Total........ | ...... | ...... | ...... | 2,495.8 | ...... | 392.69 | ...... | 565.81 | ...... | 86.72 | ...... | 5,875.7 |
| Average (7 days) | ...... | ...... | ...... | 356.5 | ...... | 56.1 | ...... | 80.8 | ...... | 12.4 | ...... | 839.4 |
| **Steer B:** | | | | | | | | | | | | |
| Collected........ | 21,265.0 | 1.044 | 9.595 | 2,040.4 | 1.246 | 264.96 | 2.603 | 553.53 | .451 | 95.91 | .2587 | 5,501.8 |
| Spilled, May 5... | 408.3 | ...... | 13.973 | 57.1 | 1.814 | 7.41 | 3.790 | 15.47 | .657 | 2.68 | .3766 | 153.8 |
| Spilled, May 5... | 2,036.0 | ...... | .913 | 18.6 | .119 | 2.42 | .249 | 5.07 | .043 | .88 | .0247 | 50.3 |
| Total........ | ...... | ...... | ...... | 2,116.1 | ...... | 274.79 | ...... | 574.07 | ...... | 99.47 | ...... | 5,715.4 |
| Average (9 days) | ...... | ...... | ...... | 235.1 | ...... | 30.5 | ...... | 63.8 | ...... | 11.1 | ...... | 635.0 |
| *Period III.* | | | | | | | | | | | | |
| **Steer A:** | | | | | | | | | | | | |
| Collected........ | 35,995.0 | 1.022 | 5.086 | 1,830.7 | .389 | 140.02 | 1.146 | 412.50 | .154 | 55.43 | .1087 | 3,912.7 |
| Spilled, Mar. 10.. | 256.9 | ...... | 3.561 | 9.1 | .272 | .70 | .801 | 2.06 | .108 | .28 | .0761 | 19.6 |
| Total........ | ...... | ...... | ...... | 1,839.8 | ...... | 140.72 | ...... | 414.56 | ...... | 55.71 | ...... | 3,932.3 |
| Average (10 days) | ...... | ...... | ...... | 184.0 | ...... | 14.1 | ...... | 41.5 | ...... | 5.6 | ...... | 393.2 |
| **Steer B:** | | | | | | | | | | | | |
| Collected........ | 14,665.0 | ...... | 8.861 | 1,299.5 | 1.155 | 169.38 | 2.570 | 376.89 | .382 | 56.02 | .2460 | 3,607.6 |
| Average (10 days) | ...... | ...... | ...... | 130.0 | ...... | 16.9 | ...... | 37.7 | ...... | 5.6 | ...... | 360.8 |
| *Period IV.* | | | | | | | | | | | | |
| **Steer A:** | | | | | | | | | | | | |
| Collected........ | 23,015.0 | 1.037 | 7.905 | 1,819.3 | .601 | 138.32 | 2.396 | 551.44 | .277 | 63.75 | .2193 | 5,047.2 |
| Spilled, Mar. 25.. | 196.2 | ...... | 12.693 | 24.9 | .966 | 1.90 | 3.851 | 7.56 | .445 | .87 | .3525 | 69.2 |
| Total........ | ...... | ...... | ...... | 1,844.2 | ...... | 140.22 | ...... | 559.00 | ...... | 64.62 | ...... | 5,116.4 |
| Average (10 days) | ...... | ...... | ...... | 184.4 | ...... | 14.0 | ...... | 55.9 | ...... | 6.5 | ...... | 511.6 |
| **Steer B:** | | | | | | | | | | | | |
| Collected........ | 15,525.0 | 1.043 | 8.829 | 1,370.7 | .793 | 123.11 | 2.610 | 405.20 | .394 | 61.17 | .2428 | 3,769.5 |
| Spilled, Mar. 23.. | 2,388.1 | ...... | 1.306 | 31.2 | .117 | 2.79 | .385 | 9.19 | .058 | 1.39 | .0358 | 85.5 |
| Total........ | ...... | ...... | ...... | 1,401.9 | ...... | 125.90 | ...... | 414.39 | ...... | 62.56 | ...... | 3,855.0 |
| Average (10 days) | ...... | ...... | ...... | 140.2 | ...... | 12.6 | ...... | 41.4 | ...... | 6.3 | ...... | 385.5 |

The foregoing results are summarized for convenience in Table 80.

TABLE 80.—*Average daily excretion in urine, 1905.*

| Periods. | Nitrogen. | Carbon. | Energy. | Energy per gram carbon. |
|---|---|---|---|---|
| *Steer A.* | *Grams.* | *Grams.* | *Calories.* | *Calories.* |
| I | 34.2 | 60.1 | 613.5 | 10.21 |
| II | 56.1 | 80.8 | 839.4 | 10.39 |
| III | 14.1 | 41.5 | 393.2 | 9.47 |
| IV | 14.0 | 55.9 | 511.6 | 9.15 |
| *Steer B.* | | | | |
| I | 29.6 | 50.2 | 522.3 | 10.40 |
| II | 30.5 | 63.8 | 635.0 | 9.95 |
| III | 16.9 | 37.7 | 360.8 | 9.57 |
| IV | 12.6 | 41.4 | 385.5 | 9.31 |

## PRODUCTION OF EPIDERMAL TISSUE.

The steer was thoroughly brushed immediately before entering the calorimeter and after leaving it, and the hair, dandruff, etc., in the latter case collected. To this was added the small amount brushed up from the floor of the calorimeter. In these samples determinations of nitrogen, carbon, and energy were made with the following results:

TABLE 81.—*Weight and composition of brushings for the two days in the calorimeter, 1905.*

| | Period I. | | Period II. | | Period III. | | Period IV. | |
|---|---|---|---|---|---|---|---|---|
| | Steer A. | Steer B. | Steer A. | Steer B. | Steer A. | Steer B. | Steer A. | Steer B. |
| Weight ... grams | 39.2 | 46.2 | 54.7 | 14.9 | 25.4 | 22.5 | 41.6 | 38.0 |
| Dry matter ... per cent | 94.27 | 92.46 | 92.65 | 81.72 | 94.72 | 95.29 | 90.87 | 91.86 |
| Weight of dry matter ... grams | 37.0 | 42.7 | 50.7 | 12.2 | 24.1 | 21.4 | 37.8 | 34.9 |
| In dry matter: | | | | | | | | |
| Nitrogen— | | | | | | | | |
| Percentage | 5.244 | 4.441 | 7.681 | 4.660 | 5.426 | 6.046 | 7.322 | 6.562 |
| Weight ... grams | 1.94 | 1.89 | 3.89 | .57 | 1.31 | 1.29 | 2.77 | 2.29 |
| Carbon— | | | | | | | | |
| Percentage | 36.391 | 40.490 | 42.657 | ........ | 39.629 | 40.600 | 43.360 | 39.412 |
| Weight ... grams | 13.45 | 17.28 | 21.63 | ........ | 9.53 | 8.69 | 16.39 | 13.75 |
| Hydrogen— | | | | | | | | |
| Percentage | 4.627 | 5.258 | 5.538 | ........ | 4.682 | 4.743 | 5.576 | 4.548 |
| Weight ... grams | 1.71 | 2.25 | 2.81 | ........ | 1.13 | 1.02 | 2.11 | 1.59 |
| Energy— | | | | | | | | |
| Calories per gram | 4.1925 | 4.3659 | 4.7535 | ........ | 4.2791 | 4.4601 | 4.6748 | 4.3371 |
| Total ... calories | 153.0 | 186.4 | 241.0 | ........ | 103.0 | 95.4 | 176.7 | 151.4 |

### ESTIMATED GROWTH OF HAIR.

The growth of hair was not determined in the experiments of 1905, but the dry matter in the average daily growth in the experiments of 1906 and 1907 was approximately proportional to the relative surface of the animals as computed in proportion to the two-thirds power of the live weight, except in the case of steer B in 1906, in which the observed result was considerably less than the estimated. Taking the results for steer A in 1907 as the basis of computation as a matter of convenience, Table 82 gives a comparison of actual and estimated daily growth in each series of experiments.

TABLE 82.—*Estimated growth of hair.*

| Years. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Approximate live weight. | Dry matter in daily growth of hair. | | Approximate live weight. | Dry matter in daily growth of hair. | |
| | | Actual. | Estimated. | | Actual. | Estimated. |
| | *Kilos.* | *Grams.* | *Grams.* | *Kilos.* | *Grams.* | *Grams.* |
| 1905 | 270 | ............ | 3.38 | 200 | ............ | 2.76 |
| 1906 | 400 | 4.76 | 4.39 | 300 | 2.54 | 3.62 |
| 1907 | 500 | 5.09 | 5.09 | 375 | 4.29 | 4.20 |

Applying to the estimated daily growth in 1905 the average percentages of nitrogen, carbon, and hydrogen and the average heats of combustion found for both animals in both the other years, we obtain the estimate shown in Table 83 for the amounts of the several elements and of energy contained in the daily growth of hair. These, added to the amounts contained in the brushings, give the average daily production of epidermal tissue which is used in the balance tables on subsequent pages.

TABLE 83.—*Average daily production of epidermal tissue, 1905.*

| Components. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | In estimated growth of hair. | In brushings. | Total. | In estimated growth of hair. | In brushings. | Total. |
| Dry matter..........grams.. | 3.38 | 18.70 | 22.08 | 2.76 | 13.90 | 16.66 |
| Nitrogen..........do.... | .50 | 1.24 | 1.74 | .41 | .76 | 1.17 |
| Carbon..........do.... | 1.65 | 7.63 | 9.28 | 1.34 | 6.62 | 7.96 |
| Hydrogen..........do.... | .24 | .97 | 1.21 | .19 | .81 | 1.00 |
| Energy..........calories.. | 17.95 | 83.70 | 101.65 | 14.65 | 72.20 | 86.85 |

## DETERMINATION OF RESPIRATORY PRODUCTS.

At about 1 p. m. on the sixth day of the 10 during which the excreta were collected, the animal was placed in the respiration calorimeter and the air current started. During the following 5 hours the necessary adjustments of the calorimeter were made, and beginning at 6 p. m. the respiratory products, as well as the heat evolved, were measured for the succeeding 48 hours, the time being divided into subperiods of 12 hours each. In other words, the respiration experiments covered the seventh and eighth days out of the 10 (or the fourteenth and fifteenth out of the 18 included in Period I, steer A).

In previous publications the data of the respiration determinations have been given in considerable detail. In Part III of this report the technic of the respiration experiments is described and illustrated by the detailed figures of one subperiod. It has not seemed necessary, however, to occupy space with a complete tabulation of these results for each subperiod, since at best they could scarcely serve any other purpose than verification of the arithmetical accuracy of the calculations. These calculations have been checked independently by two computers and are believed to be substantially correct, while the complete records of the experiments will be carefully preserved in the files of the Institute. Table 84 shows the results obtained for the excretion of carbon and hydrogen in the forms of carbon dioxid, water, and hydrocarbon gases for each subperiod, together with the ratio of hydrogen to carbon in the combustible gases excreted.

**Table 84.**—*Carbon and hydrogen in gaseous excreta, 1905.*

| Periods. | In $CO_2$ and $H_2O$. | | In hydrocarbons. | | $CH_4$ computed from C. | H : C in hydrocarbons. |
|---|---|---|---|---|---|---|
| | Carbon. | Hydrogen. | Carbon. | Hydrogen. | | |
| *Period I.* | | | | | | |
| Steer A, Jan. 18 and 19: | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | 1: |
| Subperiod 1 | 461.4 | 346.4 | 30.98 | 10.21 | 41.4 | 3.035 |
| Subperiod 2 | 457.2 | 332.0 | 31.29 | 10.31 | 41.8 | 3.035 |
| First day | 918.6 | 678.4 | 62.27 | 20.52 | 83.2 | 3.035 |
| Subperiod 3 | 407.2 | 286.6 | 30.84 | 10.16 | 41.1 | 3.036 |
| Subperiod 4 | 419.8 | 271.4 | 30.93 | 10.19 | 41.3 | 3.036 |
| Second day | 827.0 | 558.0 | 61.77 | 20.35 | 82.4 | 3.036 |
| Average | 872.8 | 618.2 | 62.02 | 20.44 | 82.8 | 3.035 |
| Steer B, Jan. 25 and 26: | | | | | | |
| Subperiod 1 | 327.1 | 163.2 | 22.89 | 8.04 | 30.6 | 2.847 |
| Subperiod 2 | 356.0 | 189.5 | 24.03 | 7.84 | 32.1 | 3.065 |
| First day | 683.1 | 352.7 | 46.92 | 15.88 | 62.7 | 2.955 |
| Subperiod 3 | 356.6 | 204.5 | 24.52 | 7.66 | 32.8 | 3.201 |
| Subperiod 4 | 372.8 | 192.0 | 27.17 | 8.54 | 36.3 | 3.182 |
| Second day | 729.4 | 396.5 | 51.69 | 16.20 | 69.1 | 3.191 |
| Average | 706.3 | 374.6 | 49.31 | 16.04 | 65.9 | 3.074 |
| *Period II.* | | | | | | |
| Steer A, Feb. 15 and 16: | | | | | | |
| Subperiod 1 | 484.5 | 287.4 | 38.68 | 12.31 | 51.7 | 3.142 |
| Subperiod 2 | 511.8 | 296.0 | 40.12 | 12.87 | 53.6 | 3.117 |
| First day | 996.3 | 583.4 | 78.80 | 25.18 | 105.3 | 3.129 |
| Subperiod 3 | 489.6 | 330.1 | 39.27 | 12.80 | [1] 52.5 | 3.068 |
| Subperiod 4 | 543.4 | 336.1 | 40.47 | 12.92 | 54.1 | 3.132 |
| Second day | 1,033.0 | 666.2 | 79.74 | 25.72 | 106.6 | 3.100 |
| Average | 1,014.7 | 624.8 | 79.27 | 25.45 | 106.0 | 3.115 |
| Steer B, May 3 and 4: | | | | | | |
| Subperiod 1 | 379.2 | 154.3 | 32.52 | 10.75 | 43.5 | 3.025 |
| Subperiod 2 | 411.8 | 164.8 | 34.48 | 11.56 | 46.1 | 2.983 |
| First day | 791.0 | 319.1 | 67.00 | 22.31 | 89.6 | 3.003 |
| Subperiod 3 | 389.5 | 175.7 | 33.23 | 10.89 | 44.4 | 3.052 |
| Subperiod 4 | 396.4 | 181.2 | 32.07 | 10.84 | 42.8 | 2.959 |
| Second day | 785.9 | 356.9 | 65.30 | 21.73 | 87.2 | 3.005 |
| Average | 788.5 | 338.0 | 66.15 | 22.02 | 88.4 | 3.004 |

[1] Pump stopped 2.23 to 3.06 a. m.

TABLE 84.—*Carbon and hydrogen in gaseous excreta, 1905*—Continued.

| Periods. | In $CO_2$ and $H_2O$. |  | In hydrocarbons. |  | $CH_4$ computed from C. | H : C in hydrocarbons. |
|---|---|---|---|---|---|---|
|  | Carbon. | Hydrogen. | Carbon. | Hydrogen. |  |  |
| *Period III.* |  |  |  |  |  |  |
| Steer A, Mar. 8 and 9: | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | 1 : |
| Subperiod 1 | 292.8 | 155.7 | 15.67 | 5.08 | 20.9 | 3.085 |
| Subperiod 2 | [1] 199.0 | 138.9 | 18.27 | 5.75 | 24.4 | 3.177 |
| First day | ........ | 294.6 | 33.94 | 10.83 | 45.3 | 3.134 |
| Subperiod 3 | 309.9 | 127.4 | 18.11 | 5.69 | 24.2 | 3.183 |
| Subperiod 4 | 307.7 | 134.1 | 17.34 | 5.33 | 23.2 | 3.253 |
| Second day | 617.6 | 261.5 | 35.45 | 11.02 | 47.4 | 3.217 |
| Average | [2] 606.9 | 278.1 | 34.70 | 10.93 | [2] 46.4 | 3.175 |
| Steer B, Feb. 22 and 23: |  |  |  |  |  |  |
| Subperiod 1 | 258.1 | 93.5 | 16.02 | 4.76 | 21.4 | 3.365 |
| Subperiod 2 | 268.9 | 103.5 | 18.19 | 5.78 | 24.3 | 3.147 |
| First day | 527.0 | 197.0 | 34.21 | 10.54 | 45.7 | 3.246 |
| Subperiod 3 | 257.8 | 95.5 | 16.91 | 5.18 | 22.6 | 3.264 |
| Subperiod 4 | 254.2 | 93.0 | 16.99 | 5.53 | 22.7 | 3.072 |
| Second day | 512.0 | 188.5 | 33.90 | 10.71 | 45.3 | 3.165 |
| Average | 519.5 | 192.8 | 34.06 | 10.63 | 45.5 | 3.204 |
| *Period IV.* |  |  |  |  |  |  |
| Steer A, Mar. 29 and 30: |  |  |  |  |  |  |
| Subperiod 1 | 395.2 | 188.6 | 29.93 | 10.74 | 40.0 | 2.787 |
| Subperiod 2 | 400.5 | 183.5 | 29.51 | 9.98 | 39.4 | 2.957 |
| First day | 795.7 | 372.1 | 59.44 | 20.72 | 79.4 | 2.869 |
| Subperiod 3 | 390.7 | 169.4 | 29.48 | 9.62 | 39.4 | 3.065 |
| Subperiod 4 | 398.9 | 173.2 | 29.68 | 9.72 | 39.7 | 3.054 |
| Second day | 789.6 | 342.6 | 59.16 | 19.34 | 79.1 | 3.059 |
| Average | 792.7 | 357.4 | 59.30 | 20.03 | 79.3 | 2.961 |
| Steer B, Mar. 22 and 23: |  |  |  |  |  |  |
| Subperiod 1 | 310.9 | 140.8 | 22.83 | 7.50 | 30.5 | 3.044 |
| Subperiod 2 | 292.3 | 129.3 | 21.79 | 7.20 | 29.1 | 3.026 |
| First day | 603.2 | 270.1 | 44.62 | 14.70 | 59.6 | 3.035 |
| Subperiod 3 | 308.7 | 149.0 | 23.00 | 7.19 | 30.7 | 3.199 |
| Subperiod 4 | 284.2 | 152.2 | 21.22 | 7.18 | 28.4 | 2.955 |
| Second day | 592.9 | 301.2 | 44.22 | 14.37 | 59.1 | 3.077 |
| Average | 598.1 | 285.7 | 44.42 | 14.54 | 59.4 | 3.055 |

[1] Probably error in determination of $CO_2$ in ingoing air.

[2] Average of 3 subperiods.

The average ratios of hydrogen to carbon in the combustible gases excreted are shown in Table 85, which justifies the assumption that they consisted chiefly or wholly of methane.

TABLE 85.—*Ratios of hydrogen to carbon in combustible gases, 1905.*

| Periods. | Steer A. | Steer B. |
|---|---|---|
|  | 1 : | 1 : |
| I | 3.035 | 3.074 |
| II | 3.115 | 3.004 |
| III | 3.175 | 3.204 |
| IV | 2.961 | 3.055 |

### THE BALANCE OF MATTER.

From the data recorded on the foregoing pages, the following tabulation of the average income and outgo of matter has been made up. Following the customary plan, the gain or loss of organic matter has been regarded as consisting wholly of protein and fat, for which the following elementary composition has been assumed:

| | Protein.[1] | Fat.[2] |
|---|---|---|
| Carbon | 52.54 | 76.5 |
| Hydrogen | 7.14 | 12.0 |
| Oxygen | 23.12 | 11.5 |
| Nitrogen | 16.67 | .......... |
| Sulphur | .52 | .......... |
| | 100.00 | 100.0 |

[1] Köhler; Ztschr. Physiol. Chem.; 31, 479.
[2] Schulze & Reinecke: Landw. Vers. Stat.; 9, 97.

In order to determine the water balance on the two respiration calorimeter days, the daily portions of the different feeding stuffs previously weighed out were reweighed very shortly before being fed, any difference being considered to represent a gain or loss of water. Special samples of the feces voided in the calorimeter were taken for the determination of dry matter. No special determinations of the urinary solids were made on the calorimeter days, but in computing the water balance, their amount is assumed to have been proportional to that of the total nitrogen. To the income of water as such is added the amount equivalent to the organic hydrogen oxidized, as shown by the balance of that element. It must be borne in mind that the water balance applies only to the two days spent in the calorimeter, while the other balances may be assumed to represent the average of the entire period.

TABLE 86.—*The balance of matter per day and head, 1905.*

| Periods and components. | Dry matter. | Water. |  | Nitrogen. |  | Carbon. |  | Organic hydrogen. |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  | Income. | Outgo. | Income. | Outgo. | Income. | Outgo. | Income. | Outgo. |
| *Period I.* |  |  |  |  |  |  |  |  |  |
| **Steer A:** | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Timothy hay | 1,977.8 | 437.0 |  | 18.0 |  | 938.2 |  | 119.1 |  |
| Wheat bran | 1,370.2 |  |  | 37.5 |  | 627.5 |  | 87.2 |  |
| Water |  | 16,478.0 |  |  |  |  |  |  |  |
| Feed residues |  |  | 112.0 |  |  |  |  |  |  |
| Feces | 1,414.2 |  | 4,565.0 |  | 22.2 |  | 666.1 |  | 77.4 |
| Urine | 216.2 |  | 3,013.0 |  | 34.2 |  | 60.1 |  | 9.0 |
| Brushings and hair | 22.1 |  |  |  | 1.7 |  | 9.3 |  | 1.2 |
| Methane | 82.8 |  |  |  |  |  | 62.0 |  | 20.7 |
| Carbon dioxid | 3,200.5 |  |  |  |  |  | 872.8 |  |  |
| Water vapor |  |  | 5,564.0 |  |  |  |  |  |  |
| Organic hydrogen oxidized |  | 1,027.0 |  |  |  |  |  |  | 114.1 |
| Gain or loss by body— |  |  |  |  |  |  |  |  |  |
| Protein | 15.6 |  |  | 2.6 |  | 8.2 |  | 1.1 |  |
| Fat | 125.3 |  |  |  |  | 96.4 |  | 15.0 |  |
| Water |  |  | 4,688.0 |  |  |  |  |  |  |
| Total |  | 17,942.0 | 17,942.0 | 58.1 | 58.1 | 1,670.3 | 1,670.3 | 222.4 | 222.4 |
| **Steer B:** |  |  |  |  |  |  |  |  |  |
| Timothy hay | 1,770.0 | 281.0 |  | 15.9 |  | 838.9 |  | 106.8 |  |
| Wheat bran | 1,032.5 |  |  | 28.7 |  | 474.7 |  | 63.4 |  |
| Water |  | 14,303.0 |  |  |  |  |  |  |  |
| Feed residues | 92.0 |  | 24.0 |  | 2.2 |  | 41.5 |  | 5.5 |
| Feces | 1,122.1 |  | 3,981.0 |  | 17.4 |  | 530.3 |  | 63.5 |
| Urine | 184.9 |  | 1,498.0 |  | 29.6 |  | 50.2 |  | 7.4 |
| Brushings and hair | 16.7 |  |  |  | 1.2 |  | 8.0 |  | 1.0 |
| Methane | 65.9 |  |  |  |  |  | 49.3 |  | 16.4 |
| Carbon dioxid | 2,590.0 |  |  |  |  |  | 706.3 |  |  |
| Water vapor |  |  | 3,372.0 |  |  |  |  |  |  |
| Organic hydrogen oxidized |  | 786.0 |  |  |  |  |  |  | 87.3 |
| Gain or loss by body— |  |  |  |  |  |  |  |  |  |
| Protein | 34.8 |  |  | 5.8 |  | 18.3 |  | 2.5 |  |
| Fat | 69.8 |  |  |  |  | 53.7 |  | 8.4 |  |
| Water |  |  | 6,495.0 |  |  |  |  |  |  |
| Total |  | 15,370.0 | 15,370.0 | 50.4 | 50.4 | 1,385.6 | 1,385.6 | 181.1 | 181.1 |
| *Period II.* |  |  |  |  |  |  |  |  |  |
| **Steer A:** |  |  |  |  |  |  |  |  |  |
| Timothy hay | 1,995.6 | 825.0 |  | 18.0 |  | 938.7 |  | 120.4 |  |
| Wheat bran | 2,583.2 |  |  | 71.5 |  | 1,181.6 |  | 165.1 |  |
| Water |  | 10,600.0 |  |  |  |  |  |  |  |
| Feed residues |  |  | 50.0 |  |  |  |  |  |  |
| Feces | 1,789.6 |  | 7,416.0 |  | 29.9 |  | 844.0 |  | 104.4 |
| Urine | 356.5 |  | 3,811.0 |  | 56.1 |  | 80.8 |  | 12.4 |
| Brushings and hair | 22.1 |  |  |  | 1.7 |  | 9.3 |  | 1.2 |
| Methane | 106.0 |  |  |  |  |  | 79.3 |  | 26.4 |
| Carbon dioxid | 3,720.8 |  |  |  |  |  | 1,014.7 |  |  |
| Water vapor |  |  | 5,623.0 |  |  |  |  |  |  |
| Organic hydrogen oxidized |  | 1,141.0 |  |  |  |  |  |  | 126.8 |
| Gain or loss by body— |  |  |  |  |  |  |  |  |  |
| Protein | 10.8 |  |  |  | 1.8 |  | 5.7 |  | .8 |
| Fat | 112.5 |  |  |  |  |  | 86.5 |  | 13.5 |
| Water |  | 4,334.0 |  |  |  |  |  |  |  |
| Total |  | 16,900.0 | 16,900.0 | 89.5 | 89.5 | 2,120.3 | 2,120.3 | 285.5 | 285.5 |
| **Steer B:** |  |  |  |  |  |  |  |  |  |
| Timothy hay | 1,779.0 | 425.0 |  | 17.5 |  | 841.1 |  | 130.6 |  |
| Wheat bran | 1,802.6 |  |  | 48.2 |  | 800.0 |  | 128.9 |  |
| Water |  | 7,425.0 |  |  |  |  |  |  |  |
| Feed residues |  |  |  |  |  |  |  |  |  |
| Feces | 1,376.2 |  | 5,811.0 |  | 22.4 |  | 636.0 |  | 92.9 |
| Urine | 235.1 |  | 2,179.0 |  | 30.5 |  | 63.8 |  | 11.1 |
| Brushings and hair | 16.7 |  |  |  | 1.2 |  | 8.0 |  | 1.0 |
| Methane | 88.4 |  |  |  |  |  | 66.2 |  | 22.1 |
| Carbon dioxid | 2,891.3 |  |  |  |  |  | 788.5 |  |  |
| Water vapor |  |  | 3,017.0 |  |  |  |  |  |  |
| Organic hydrogen oxidized |  | 1,087.0 |  |  |  |  |  |  | 120.8 |
| Gain or loss by body— |  |  |  |  |  |  |  |  |  |
| Protein | 69.6 |  |  |  | 11.6 |  | 36.6 |  | 5.0 |
| Fat | 54.6 |  |  |  |  |  | 42.0 |  | 6.6 |
| Water |  | 2,070.0 |  |  |  |  |  |  |  |
| Total |  | 11,007.0 | 11,007.0 | 65.7 | 65.7 | 1,641.1 | 1,641.1 | 259.5 | 259.5 |

TABLE 86.—*The balance of matter per day and head, 1905*—Continued.

| Period and component. | Dry matter. | Water. |  | Nitrogen. |  | Carbon. |  | Organic hydrogen. |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  | Income. | Outgo. | Income. | Outgo. | Income. | Outgo. | Income. | Outgo. |
| *Period III.* |  |  |  |  |  |  |  |  |  |
| **Steer A:** | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Timothy hay | 2,001.0 | 187.0 |  | 19.5 |  | 945.9 |  | 126.7 |  |
| Water |  | 4,952.0 |  |  |  |  |  |  |  |
| Feed residues |  |  |  |  |  |  |  |  |  |
| Feces | 909.2 |  | 3,738.0 |  | 12.5 |  | 459.7 |  | 52.5 |
| Urine | 184.0 |  | 2,197.0 |  | 14.1 |  | 41.5 |  | 5.6 |
| Brushings and hair | 22.1 |  |  |  | 1.7 |  | 9.3 |  | 1.2 |
| Methane | 46.4 |  |  |  |  |  | 34.7 |  | 11.6 |
| Carbon dioxid | [1] 2,225.5 |  |  |  |  |  | [1] 606.9 |  |  |
| Water vapor |  |  | 2,478.0 |  |  |  |  |  |  |
| Organic hydrogen oxidized |  | 787.0 |  |  |  |  |  |  | 87.4 |
| Gain or loss by body— |  |  |  |  |  |  |  |  |  |
| Protein | 52.8 |  |  | 8.8 |  | 27.7 |  | 3.8 |  |
| Fat | 232.0 |  |  |  |  | 178.5 |  | 27.8 |  |
| Water |  | 2,487.0 |  |  |  |  |  |  |  |
| Total |  | 8,413.0 | 8,413.0 | 28.3 | 28.3 | 1,152.1 | 1,152.1 | 158.3 | 158.3 |
| **Steer B:** |  |  |  |  |  |  |  |  |  |
| Timothy hay | 1,773.8 | 83.0 |  | 16.0 |  | 834.4 |  | 107.0 |  |
| Water |  | 3,952.0 |  |  |  |  |  |  |  |
| Feed residues |  |  |  |  |  |  |  |  |  |
| Feces | 800.7 |  | 3,154.0 |  | 12.7 |  | 401.1 |  | 47.2 |
| Urine | 130.0 |  | 1,303.0 |  | 16.9 |  | 37.7 |  | 5.6 |
| Brushings and hair | 16.7 |  |  |  | 1.2 |  | 8.0 |  | 1.0 |
| Methane | 45.5 |  |  |  |  |  | 34.1 |  | 11.4 |
| Carbon dioxid | 1,905.0 |  |  |  |  |  | 519.5 |  |  |
| Water vapor |  |  | 1,734.0 |  |  |  |  |  |  |
| Organic hydrogen oxidized |  | 600.0 |  |  |  |  |  |  | 66.7 |
| Gain or loss by body— |  |  |  |  |  |  |  |  |  |
| Protein | 88.8 |  |  | 14.8 |  | 46.7 |  | 6.3 |  |
| Fat | 155.1 |  |  |  |  | 119.3 |  | 18.6 |  |
| Water |  | 1,556.0 |  |  |  |  |  |  |  |
| Total |  | 6,191.0 | 6,191.0 | 30.8 | 30.8 | 1,000.4 | 1,000.4 | 131.9 | 131.9 |
| *Period IV.* |  |  |  |  |  |  |  |  |  |
| **Steer A:** |  |  |  |  |  |  |  |  |  |
| Timothy hay | 3,493.1 | 322.0 |  | 29.0 |  | 1,641.2 |  | 210.7 |  |
| Water |  | 8,135.0 |  |  |  |  |  |  |  |
| Feed residues |  |  |  |  |  |  |  |  |  |
| Feces | 1,681.6 |  | 7,074.0 |  | 21.8 |  | 835.3 |  | 115.4 |
| Urine | 184.4 |  | 2,054.0 |  | 14.0 |  | 55.9 |  | 6.5 |
| Brushings and hair | 22.1 |  |  |  | 1.7 |  | 9.3 |  | 1.2 |
| Methane | 79.3 |  |  |  |  |  | 59.3 |  | 19.8 |
| Carbon dioxid | 2,906.8 |  |  |  |  |  | 792.7 |  |  |
| Water vapor |  |  | 3,216.0 |  |  |  |  |  |  |
| Organic hydrogen oxidized |  | 761.0 |  |  |  |  |  |  | 84.6 |
| Gain or loss by body— |  |  |  |  |  |  |  |  |  |
| Protein | 51.0 |  |  | 8.5 |  | 26.8 |  | 3.6 |  |
| Fat | 109.9 |  |  |  |  | 84.5 |  | 13.2 |  |
| Water |  | 3,126.0 |  |  |  |  |  |  |  |
| Total |  | 12,344.0 | 12,344.0 | 37.5 | 37.5 | 1,752.5 | 1,752.5 | 227.5 | 227.5 |
| **Steer B:** |  |  |  |  |  |  |  |  |  |
| Timothy hay | 2,657.4 | 229.0 |  | 24.4 |  | 1,248.1 |  | 150.9 |  |
| Water |  | 285.0 |  |  |  |  |  |  |  |
| Feed residues | 47.8 |  | 6.0 |  | .6 |  | 23.2 |  |  |
| Feces | 1,174.6 |  | 3,925.0 |  | 18.0 |  | 584.2 |  | 67.0 |
| Urine | 140.2 |  | 1,405.0 |  | 12.6 |  | 41.4 |  | 6.3 |
| Brushings and hair | 16.7 |  |  |  | 1.2 |  | 8.0 |  | 1.0 |
| Methane | 59.4 |  |  |  |  |  | 44.4 |  | 14.8 |
| Carbon dioxid | 2,193.1 |  |  |  |  |  | 598.1 |  |  |
| Water vapor |  |  | 2,571.0 |  |  |  |  |  |  |
| Organic hydrogen oxidized |  | 624.0 |  |  |  |  |  |  | 69.3 |
| Gain or loss by body— |  |  |  |  |  |  |  |  |  |
| Protein | 48.0 |  |  | 8.0 |  | 25.2 |  | 3.4 |  |
| Fat | 33.8 |  |  |  |  | 26.0 |  | 4.1 |  |
| Water |  | 6,769.0 |  |  |  |  |  |  |  |
| Total |  | 7,907.0 | 7,907.0 | 32.4 | 32.4 | 1,299.3 | 1,299.3 | 158.4 | 158.4 |

[1] From only 3 subperiods.

### COMPUTED GAINS OR LOSSES OF LIVE WEIGHT IN THE CALORIMETER.

The results of the heat determinations recorded on subsequent pages, as is there pointed out, require a correction for the amount of matter gained or lost by the body of the animal. In the absence of direct determinations of the oxygen consumed, these gains or losses by the body have been computed in Table 86 on the usual assumption that its small content of carbohydrates remained substantially unchanged and that the gains or losses of organic matter may be regarded as consisting of protein or fat. The ash of the urine not having been determined, it is not possible to compute an ash balance, but this omission does not render the results seriously erroneous for the purpose here in view.

Subject to these relatively small uncertainties, the data of Table 86 show the single factors which make up the gain or loss of live weight during the days spent in the calorimeter. To the results as thus computed there must be added a correction for irregularity of excretion, especially of the feces. In computing the balances of nitrogen, carbon, and hydrogen, the average excretion of dry matter as determined in the 10-day digestion period is rightly made the basis of calculation. The actual amount of dry matter excreted during the two days in the respiration calorimeter, however, differs somewhat from this average. While the differences are relatively insignificant, they are entered as corrections in the proper column of Table 87.

TABLE 87.—*Computed daily gains or losses of live weight in the calorimeter, 1905.*

| | Period I. | | Period II. | | Period III. | | Period IV. | |
|---|---|---|---|---|---|---|---|---|
| | Loss. | Gain. | Loss. | Gain. | Loss. | Gain. | Loss. | Gain. |
| *Steer A.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Protein[1] | 16 | | | 11 | 53 | | 51 | |
| Fat | 125 | | | 113 | 232 | | 110 | |
| Water | | 4,688 | 4,334 | | 2,487 | | 3,126 | |
| Correction for irregularity of excretion | | 344 | | 108 | | 25 | | 80 |
| Balance | 4,891 | | | 4,102 | | 2,747 | | 3,207 |
| | 5,032 | 5,032 | 4,334 | 4,334 | 2,772 | 2,772 | 3,287 | 3,287 |
| *Steer B.* | | | | | | | | |
| Protein | 35 | | | 70 | 89 | | 48 | |
| Fat | 70 | | | 55 | 155 | | 34 | |
| Water | | 6,495 | 2,070 | | 1,556 | | 6,769 | |
| Correction for irregularity of excretion | | 176 | 86 | | | 30 | | 176 |
| Balance | 6,566 | | | 2,031 | | 1,770 | | 6,675 |
| | 6,671 | 6,671 | 2,156 | 2,156 | 1,800 | 1,800 | 6,851 | 6,851 |

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[1] Computed from nitrogen, using the factors stated in Part III, page 203.

Our apparatus does not permit of weighing the animal while in the respiration chamber, so that the observed gains or losses of weight cover the four or five preliminary hours in the calorimeter. A comparison of the computed with the observed changes in live weight for this whole time, however, in the manner described in connection with the experiments of 1906 (pp. 145–147), gives the following results, which show a fairly good agreement:

TABLE 88.—*Computed and observed gains in live weight in the calorimeter, 1905.*

| Periods. | Computed. | Observed. |
|---|---|---|
| | *Kilos.* | *Kilos.* |
| Period I: | | |
| Steer A | (1) | − 5.6 |
| Steer B | (1) | +10.4 |
| Period II: | | |
| Steer A | −13.5 | −17.5 |
| Steer B | − 5.2 | − 9.2 |
| Period III: | | |
| Steer A | − 7.3 | − 8.8 |
| Steer B | − 4.6 | − 4.0 |
| Period IV: | | |
| Steer A | − 9.4 | −10.6 |
| Steer B | −15.1 | −15.9 |

(1) Records incomplete.

## HEAT EMISSION.

The results of the determinations of heat, made in the manner described in Part III of this bulletin, pages 205–216, are contained in the following table. That portion of the heat given off by radiation and conduction and brought out of the calorimeter in the water current is recorded for each animal in the column headed "Radiation," while the second column shows the amount carried off as latent heat of water vapor. The small corrections necessary for feed, excreta, etc., put into and taken out of the calorimeter have been made upon the heat given off by radiation.

TABLE 89.—*Heat emission.*

| Periods. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | By radiation. | As latent heat of water vapor. | Total. | By radiation. | As latent heat of water vapor. | Total. |
| *Period I.* | | | | | | |
| First day: | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Subperiod 1 | 2,823.0 | 1,845.8 | 4,668.8 | 2,079.6 | 869.4 | 2,949.0 |
| Subperiod 2 | 2,578.6 | 1,769.0 | 4,347.6 | 2,132.3 | 1,009.9 | 3,142.2 |
| Total | 5,401.6 | 3,614.8 | 9,016.4 | 4,211.9 | 1,879.3 | 6,091.2 |
| Second day: | | | | | | |
| Subperiod 3 | 2,500.7 | 1,526.7 | 4,027.4 | 2,390.7 | 1,089.7 | 3,480.4 |
| Subperiod 4 | 2,534.8 | 1,446.0 | 3,980.8 | 2,385.8 | 1,022.9 | 3,408.7 |
| Total | 5,035.5 | 2,972.7 | 8,008.2 | 4,776.5 | 2,112.6 | 6,889.1 |
| Daily average | 5,218.6 | 3,293.8 | 8,512.3 | 4,494.2 | 1,996.0 | 6,490.2 |
| *Period II.* | | | | | | |
| First day: | | | | | | |
| Subperiod 1 | 3,120.5 | 1,531.4 | 4,651.9 | 3,339.4 | 822.0 | 4,161.4 |
| Subperiod 2 | 2,822.3 | 1,576.8 | 4,399.1 | 2,485.1 | 877.9 | 3,363.0 |
| Total | 5,942.8 | 3,108.2 | 9,051.0 | 5,824.5 | 1,699.9 | 7,524.4 |
| Second day: | | | | | | |
| Subperiod 3 | 3,038.1 | 1,758.8 | 4,796.9 | 3,717.7 | 936.0 | 3,653.7 |
| Subperiod 4 | 2,837.7 | 1,790.7 | 4,628.4 | 2,595.5 | 965.5 | 3,561.0 |
| Total | 5,875.8 | 3,549.5 | 9,425.3 | 5,313.2 | 1,901.5 | 7,214.7 |
| Daily average | 5,909.3 | 3,328.9 | 9,238.2 | 5,568.9 | 1,800.7 | 7,369.6 |
| *Period III.* | | | | | | |
| First day: | | | | | | |
| Subperiod 1 | 2,434.4 | 829.7 | 3,264.1 | 2,484.6 | 498.0 | 2,982.6 |
| Subperiod 2 | 2,417.0 | 740.3 | 3,157.3 | 2,166.5 | 551.4 | 2,717.9 |
| Total | 4,851.4 | 1,570.0 | 6,421.4 | 4,651.1 | 1,049.4 | 5,700.5 |
| Second day: | | | | | | |
| Subperiod 3 | 2,308.6 | 678.8 | 2,987.4 | 1,947.7 | 509.0 | 2,456.7 |
| Subperiod 4 | 2,382.0 | 714.3 | 3,096.3 | 1,861.3 | 495.4 | 2,356.7 |
| Total | 4,690.6 | 1,393.1 | 6,083.7 | 3,809.0 | 1,004.4 | 4,813.4 |
| Daily average | 4,771.0 | 1,481.6 | 6,252.6 | 4,230.1 | 1,026.9 | 5,257.0 |
| *Period IV.* | | | | | | |
| First day: | | | | | | |
| Subperiod 1 | 2,920.9 | 1,004.9 | 3,925.8 | 1,840.4 | 750.3 | 2,590.7 |
| Subperiod 2 | 2,783.3 | 977.8 | 3,761.1 | 2,107.6 | 689.1 | 2,796.7 |
| Total | 5,704.2 | 1,982.7 | 7,686.9 | 3,948.0 | 1,439.4 | 5,387.4 |
| Second day: | | | | | | |
| Subperiod 1 | 2,760.2 | 902.5 | 3,662.7 | 2,149.7 | 793.9 | 2,943.6 |
| Subperiod 2 | 2,578.6 | 922.7 | 3,501.3 | 2,017.0 | 810.8 | 2,827.8 |
| Total | 5,338.8 | 1,825.2 | 7,164.0 | 4,166.7 | 1,604.7 | 5,771.4 |
| Daily average | 5,521.5 | 1,904.0 | 7,425.5 | 4,057.4 | 1,522.1 | 5,579.4 |

## HEAT PRODUCTION.

The figures of Table 89 show the amounts of heat given off daily by the animals, but these are not necessarily equal to the amounts actually produced in the same time, since heat may, on the one hand, be retained in the body, or, on the other hand, heat produced previous to an experimental period may be eliminated during that period.

*Variations in body temperature.*—While the body temperature of a healthy animal is approximately constant, it is, nevertheless, subject to minor variations which in the case of man are of a distinctly periodic character. So far as the writers are aware no similar observations are on record for cattle. The rectal temperatures as recorded in the appendix were taken about 1 p. m., except upon the respiration calorimeter days, and show considerable fluctuation, the extreme range being from 0.5° to 1.0° C., while nearly as great variations are observed in some instances from one day to the next. A rise of body temperature is, of course, equivalent to the storage of a corresponding amount of heat, while, conversely, a fall of temperature is equivalent to the emission of heat previously produced. If the extreme range of 1.0° C. occurred between the beginning and end of a calorimeter experiment, the resulting error in these experiments, assuming a specific heat of 0.8 for the whole body, would be equivalent to about 200 calories for steer A and about 160 calories for steer B. Whether such extreme variations actually took place, the data are insufficient to show. A study of the temperature records shows some peculiar irregularities. In many cases, the body temperature is approximately the same for several successive days and then suddenly for one or two days shows a striking difference. The cattle gave no indications of illness and the results raise a question as to the reliability of the rectal temperature as an index of the true body temperature of these animals. In view of these uncertainties and since, moreover, the temperatures taken at 6 p. m. at the end of the calorimeter runs may not be comparable with those taken at a different hour during the remainder of the experiment, we have not attempted to compute any correction, but content ourselves with calling attention to this source of error.

*Gain or loss of matter by the body.*—Even if the body maintains a uniform temperature, a gain or loss of matter is equivalent to a gain or loss of heat, since the food, drink, and excreta are reduced to the temperature of the calorimeter actually or by calculation. The data recorded in Table 87 show the nature of these gains and losses and enable a correction to be computed. In the computation of this correction, the temperature of the animal has been regarded as represented by the average body temperature for the period. The specific heat of the fat and protein gained is based on Rosenthal's results.[1] He finds a specific heat of approximately 0.3 for dry muscle tissue and of 0.72 for fat tissue. If we assume the latter to contain 15 per cent of water and 85 per cent of fat, neglecting the small amount of fat-free dry matter, Rosenthal's figure is equivalent to a specific heat of 0.66 for fat. The small correction for the irregular excretion of dry matter may be neglected as entirely insignificant for the purpose of the calculation. Using Period I, steer A, as an illustration, the calculation is as follows:

---

[1] Arch. (anat. u.) Physiol.; 1867, p. 215.

*Period I.—Steer A.*

[Average body temperature, 37.6° C. Calorimeter temperature, 17.2° C.]

Protein $-0.016$ kilos $\times 0.30 \times 20.4 = -$ 0.10 calories.
Fat $-0.125$ kilos $\times 0.66 \times 20.4 = -$ 1.68 calories.
Water $+4.688$ kilos $\times 1.00 \times 20.4 = +95.64$ calories.

Correction............... +93.86 calories.

In Table 90 the heat actually produced by the animals has been computed by applying the correction computed as just illustrated to the figures for heat emission contained in Table 89. The results are, of course, still subject to the uncertainty above mentioned regarding the influence of changes in body temperature.

TABLE 90.—*Average heat production, 1905.*

| Periods. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Heat emission. | Correction for gain by body. | Heat production. | Heat emission. | Correction for gain by body. | Heat production. |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| I | 8,512.3 | +93.9 | 8,606.2 | 6,490.2 | +130.7 | 6,620.9 |
| II | 9,238.2 | −89.4 | 9,148.8 | 7,369.6 | − 43.1 | 7,326.5 |
| III | 6,252.6 | −56.3 | 6,196.3 | 5,257.0 | − 35.6 | 5,221.4 |
| IV | 7,425.5 | −69.1 | 7,356.4 | 5,579.4 | −145.0 | 5,434.4 |

## THE BALANCE OF ENERGY.

The following table shows the energy balance for each period of the experiments, assuming the average heat values of 5.7 calories and 9.5 calories per gram, respectively, for the gains of protein and fat shown by the nitrogen and carbon balances of Table 86 and reckoning 13.344 calories per gram of methane. The energy balance has been divided for convenience so as to show also the metabolizable energy of each ration. Before making the latter computation, however, it is necessary to correct the potential energy of the urine for the gain or loss of nitrogen, since in case of a loss of nitrogen, the urine contains energy derived from body tissue, while in the contrary case energy which would have appeared in the urine is retained in the body. The energy of the urine has accordingly been corrected to nitrogen equilibrium by adding or subtracting Rubner's figure of 7.45 calories for each gram of nitrogen gained or lost by the body. This having been done, however, the same correction must be made in the computed energy of the protein gained or lost by the animal in order to be able to compare the metabolizable energy with the gain by the animal. In the table following these corrections have been made.

TABLE 91.—*The balance of energy per day and head, 1905.*

| | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Dry matter. | Energy. | | Dry matter. | Energy. | |
| | | Income. | Outgo. | | Income. | Outgo. |
| *Period I.* | *Grams.* | *Calories.* | *Calories.* | *Grams.* | *Calories.* | *Calories.* |
| Timothy hay | 1,977.8 | 8,886.8 | | 1,770.0 | 7,948.9 | |
| Wheat bran | 1,370.2 | 6,226.6 | | 1,032.5 | 4,713.5 | |
| Uneaten residues | | | | 92.0 | | 403.8 |
| Feces | 1,414.2 | | 6,525.3 | 1,122.1 | | 5,252.6 |
| Urine (corrected for nitrogen) | 216.2 | | 594.1 | 184.9 | | 479.1 |
| Methane | 82.8 | | 1,104.9 | 65.9 | | 879.4 |
| Metabolizable | | | 6,889.1 | | | 5,647.5 |
| Total | | 15,113.4 | 15,113.4 | | 12,662.4 | 12,662.4 |
| Metabolizable | | 6,889.1 | | | 5,647.5 | |
| Heat | | | 8,606.2 | | | 6,620.9 |
| Brushings | 22.1 | | 101.7 | 16.7 | | 86.9 |
| Loss by body: | | | | | | |
| Protein (corrected for nitrogen) | 15.6 | 69.5 | | | 155.2 | |
| Fat | 125.3 | 1,190.3 | | | 663.1 | |
| Error | | 559.0 | | | 242.0 | |
| Total | | 8,707.9 | 8,707.9 | | 6,707.8 | 6,707.8 |
| *Period II.* | | | | | | |
| Timothy hay | 1,995.6 | 8,797.4 | | 1,779.0 | 7,974.5 | |
| Wheat bran | 2,583.2 | 11,775.3 | | 1,802.6 | 8,041.0 | |
| Feces | 1,789.6 | | 8,261.0 | 1,376.2 | | 6,297.9 |
| Urine (corrected for nitrogen) | 356.5 | | 852.8 | 235.1 | | 721.4 |
| Methane | 106.0 | | 1,414.5 | 88.4 | | 1,179.6 |
| Metabolizable | | | 10,044.4 | | | 7,816.6 |
| Total | | 20,572.7 | 20,572.7 | | 16,015.5 | 16,015.5 |
| Metabolizable | | 10,044.4 | | | 7,816.6 | |
| Heat | | | 9,148.8 | | | 7,326.5 |
| Brushings | 22.1 | | 101.7 | 16.7 | | 86.9 |
| Gain by body: | | | | | | |
| Protein (corrected for nitrogen) | 10.8 | | 48.2 | 69.6 | | 310.3 |
| Fat | 112.5 | | 1,068.8 | 54.6 | | 518.7 |
| Error | | 323.1 | | | 425.8 | |
| Total | | 10,367.5 | 10,367.5 | | 8,242.4 | 8,242.4 |
| *Period III.* | | | | | | |
| Timothy hay | 2,001.0 | 9,007.5 | | 1,773.8 | 7,819.6 | |
| Feces | 909.2 | | 4,419.3 | 800.7 | | 3,918.9 |
| Urine (corrected for nitrogen) | 184.0 | | 327.6 | 130.0 | | 250.6 |
| Methane | 46.4 | | 619.2 | 45.5 | | 607.2 |
| Metabolizable | | | 3,641.4 | | | 3,042.9 |
| Total | | 9,007.5 | 9,007.5 | | 7,819.6 | 7,819.6 |
| Metabolizable | | 3,641.4 | | | 3,042.9 | |
| Heat | | | 6,196.3 | | | 5,221.4 |
| Brushings | 22.1 | | 101.7 | 16.7 | | 86.9 |
| Loss by body: | | | | | | |
| Protein (corrected for nitrogen) | 5.3 | 235.4 | | 88.8 | 396.0 | |
| Fat | 232.0 | 2,204.0 | | 155.1 | 1,473.4 | |
| Error | | 217.2 | | | 396.0 | |
| Total | | 6,298.0 | 6,298.0 | | 5,308.3 | 5,308.3 |
| *Period IV.* | | | | | | |
| Timothy hay | 3,493.1 | 15,677.7 | | 2,657.4 | 11,912.6 | |
| Uneaten residues | | | | 47.8 | | 219.6 |
| Feces | 1,681.6 | | 8,055.9 | 1,174.6 | | 5,676.8 |
| Urine (corrected for nitrogen) | 184.4 | | 448.3 | 140.0 | | 325.9 |
| Methane | 79.3 | | 1,058.2 | 59.4 | | 792.6 |
| Metabolizable | | | 6,115.3 | | | 4,897.7 |
| Total | | 15,677.7 | 15,677.7 | | 11,912.6 | 11,912.6 |
| Metabolizable | | 6,115.3 | | | 4,897.7 | |
| Heat | | | 7,356.4 | | | 5,434.4 |
| Brushings | 32.1 | | 101.7 | 16.7 | | 86.9 |
| Loss by body: | | | | | | |
| Protein (corrected for nitrogen) | 51.0 | 227.4 | | 48.0 | 214.0 | |
| Fat | 109.9 | 1,044.0 | | 33.8 | 321.1 | |
| Error | | 71.4 | | | 88.5 | |
| | | 7,458.1 | 7,458.1 | | 5,521.3 | 5,521.3 |

Under the head of "Error" in the foregoing table there is shown the amount by which the gain or loss of energy by the body as determined by a comparison of the income and outgo of energy differs from that contained in the gain or loss of protein and fat as computed from the nitrogen and carbon balance, or, in other words, the extent to which the results differ from those required by the law of the conservation of energy. With the exception of Period IV, these differences are considerable, and while they may be due in part to the somewhat crude nature of the method by which the gain or loss of matter is computed, this can hardly account for the entire error. The relative magnitude of the difference would seem to be most fairly expressed by comparing the observed heat production with that computed from the balance of nitrogen and carbon, as is done in Table 92.

TABLE 92.—*Observed and computed daily heat production, 1905.*

| Periods. | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Observed. | Computed. | Error. | Computed +observed. | Observed. | Computed. | Error. | Computed +observed. |
| | *Calories.* | *Calories.* | *Calories.* | *Per cent.* | *Calories.* | *Calories.* | *Calories.* | *Per cent.* |
| I......... | 8,606.2 | 8,047.2 | −559.0 | 93.5 | 6,620.9 | 6,378.9 | −242.0 | 96.4 |
| II........ | 9,148.8 | 8,825.7 | −323.1 | 96.5 | 7,326.5 | 6,900.7 | −425.8 | 94.2 |
| III....... | 6,196.3 | 5,979.1 | −217.2 | 96.5 | 5,221.4 | 4,825.4 | −396.0 | 92.4 |
| IV....... | 7,356.4 | 7,285.0 | − 71.4 | 99.0 | 5,434.4 | 5,345.9 | − 88.5 | 98.4 |

The errors expressed in this way are relatively large and are in the opposite direction to those observed in most of our previous experiments; that is, in these experiments the observed amounts of heat are greater than correspond to the amounts of carbon dioxid and water produced. The experiments are far from being satisfactory in this respect and correspondingly less weight attaches to the results, but, nevertheless, it has seemed worth while to carry out the computation on the same plan adopted for those of the subsequent two years in which a much closer agreement was obtained. It may be added also that the conclusions regarding the availability of the energy of the feeds do not differ widely whether the observed or the computed heat production is made the basis of the comparison.

## METABOLIZABLE ENERGY.

By metabolizable energy, or fuel value, is understood the potential energy of the feed minus the potential energy of the excreta, including the gaseous excreta. The chief channel of loss of potential energy is the feces, although a considerable amount is carried off in the urine and the methane.

From Table 91 it is easy to compute in each case the percentage of the total energy which was lost in the several excreta or was metabolizable, and also, in connection with the results of the digestion trials, to compute the metabolizable energy in calories per unit of total or of digestible organic matter.

### TIMOTHY HAY.

From the energy balances of Periods III and IV the percentage distribution of the total energy of the hay and also that of the energy contained in the digested organic matter of the latter may be computed as follows:

**Table 93.**—*Percentage distribution of energy of timothy hay, 1905.*

| | Total energy. | | | Energy of digested matter. | | |
|---|---|---|---|---|---|---|
| | Period III. | Period IV. | True average. | Period III. | Period IV. | True average. |
| *Steer A.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| In feces | 49.96 | 51.38 | 50.54 | .......... | .......... | .......... |
| In urine | 3.64 | 2.86 | 3.14 | 7.15 | 5.88 | 6.35 |
| In methane | 6.87 | 6.75 | 6.80 | 13.49 | 13.88 | 13.74 |
| Metabolizable | 40.43 | 39.01 | 39.52 | 79.36 | 80.24 | 79.91 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| *Steer B.* | | | | | | |
| In feces | 50.12 | 48.55 | 49.16 | .......... | .......... | .......... |
| In urine | 3.20 | 2.79 | 2.95 | 6.42 | 5.42 | 5.81 |
| In methane | 7.76 | 6.78 | 7.17 | 15.56 | 13.17 | 14.12 |
| Metabolizable | 38.92 | 41.88 | 40.70 | 78.02 | 81.41 | 80.07 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

The metabolizable energy per gram of organic matter, total or digested, was as follows:

**Table 94.**—*Metabolizable energy per gram organic matter of timothy hay, 1905.*

| | Organic matter.[1] | | Metabolizable energy. | | |
|---|---|---|---|---|---|
| | Total. | Digested. | Total.[2] | Per gram total organic matter. | Per gram digested organic matter. |
| *Steer A.* | *Grams.* | *Grams.* | *Calories.* | *Calories.* | *Calories.* |
| Period III | 1,919.6 | 1,062.0 | 3,641.4 | 1.897 | 3.429 |
| Period IV | 3,344.3 | 1,757.4 | 6,115.3 | 1.828 | 3.480 |
| Totals and averages | 5,263.9 | 2,819.4 | 9,756.7 | 1.853 | 3.460 |
| *Steer B.* | | | | | |
| Period III | 1,698.4 | 944.7 | 3,042.9 | 1.792 | 3.221 |
| Period IV | 2,504.0 | 1,405.7 | 4,897.7 | 1.956 | 3.484 |
| Totals and averages | 4,202.4 | 2,350.4 | 7,940.6 | 1.889 | 3.378 |

[1] From Tables 74 and 76.

[2] From Table 91.

### WHEAT BRAN.

The results in Table 91 for Periods I and II show the metabolizable energy of the total rations. That of the bran alone may be computed by difference, assuming, much as in the case of a digestion experiment, that the percentages of the energy of the hay which were lost in the various excreta or which were metabolizable were the same as when the hay was fed alone. For this purpose the averages of Table 93 have been used, each animal being treated separately. As before, the results are expressed both in percentages and as calories per gram of total or digestible organic matter.

TABLE 95.—*Percentage distribution of energy of bran, 1905.*

| | Organic matter.[1] | | Total energy. | Energy of excreta. | | | Metabolizable energy. |
|---|---|---|---|---|---|---|---|
| | Total. | Digested. | | Feces. | Urine(corrected). | Methane. | |
| *Steer A.* | | | | | | | |
| Period I: | *Grams.* | *Grams.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| In total ration | 3,162.6 | 1,858.3 | 15,113.4 | 6,525.3 | 594.1 | 1,104.9 | 6,889.1 |
| In hay | 1,894.3 | 1,014.6 | 8,886.8 | 4,491.4 | 279.0 | 604.3 | 3,512.1 |
| In bran | 1,268.3 | 843.7 | 6,226.6 | 2.033.9 | 315.1 | 500.6 | 3,377.0 |
| Per cent of total energy | | | 100.0 | 32.67 | 5.06 | 8.04 | 54.24 |
| Per cent of digested energy | | | | | 7.51 | 11.94 | 80.55 |
| Period II: | | | | | | | |
| In total ration | 4,299.2 | 2,653.8 | 20,572.7 | 8,261.0 | 852.8 | 1,414.5 | 10,044.4 |
| In hay | 1,910.8 | 1,023.4 | 8,797.4 | 4,446.3 | 276.2 | 598.2 | 3,476.7 |
| In bran | 2,388.4 | 1,630.4 | 11,775.3 | 3,814.7 | 576.6 | 816.3 | 6,567.7 |
| Per cent of total energy | | | 100.0 | 32.40 | 4.90 | 6.93 | 55.77 |
| Per cent of digested energy | | | | | 7.25 | 10.25 | 82.50 |
| *Steer B.* | | | | | | | |
| Period I: | | | | | | | |
| In total ration | 2,569.8 | 1,546.1 | [2]12,258.6 | 5,252.6 | 479.1 | 879.4 | 5,647.5 |
| In hay | 1,643.2 | 919.1 | [2]7,695.4 | 3,784.6 | 227.0 | 551.8 | 3,132.0 |
| In bran | 926.6 | 627.0 | [2]4,563.2 | 1,468.0 | 252.1 | 327.6 | 2,515.5 |
| Per cent of total energy | | | 100.0 | 32.17 | 5.52 | 7.18 | 55.13 |
| Per cent of digested energy | | | | | 8.14 | 10.58 | 81.28 |
| Period II: | | | | | | | |
| In total ration | 3,365.5 | 2,119.3 | 16,015.5 | 6,297.9 | 721.4 | 1,179.6 | 7.816 6 |
| In hay | 1,697.2 | 949.2 | 7,974.5 | 3,921.9 | 235.2 | 571.8 | 3,245.6 |
| In bran | 1,668.3 | 1,170.1 | 8,041.0 | 2,376.0 | 486.2 | 607.8 | 4,571.0 |
| Per cent of total energy | | | 100.0 | 29.55 | 6.04 | 7.56 | 56.85 |
| Per cent of digested energy | | | | | 8.57 | 10.73 | 80.70 |

[1] From Tables 70, 72, and 78.

[2] Uneaten residues divided proportionally between hay and bran.

TABLE 96.—*Metabolizable energy per gram of organic matter of wheat bran, 1905.*

| Periods. | Organic matter. | | Metabolizable energy. | | |
|---|---|---|---|---|---|
| | Total. | Digested. | Total. | Per gram total organic matter. | Per gram digested organic matter. |
| *Steer A.* | *Grams.* | *Grams.* | *Calories.* | *Calories.* | *Calories.* |
| I | 1,268.3 | 843.7 | 3,377.0 | 2.663 | 4.003 |
| II | 2,388.4 | 1,630.4 | 6,567.7 | 2.749 | 4.028 |
| *Steer B.* | | | | | |
| I | 926.6 | 627.0 | 2,515.5 | 2.715 | 4.012 |
| II | 1,668.3 | 1,170.1 | 4,571.0 | 2.740 | 3.906 |

### CORRECTION OF HEAT PRODUCTION FOR STANDING AND LYING.

As has been shown by the writers in previous experiments, a very marked effect is exerted upon the heat production of cattle by standing as compared with lying. The differences are so marked that before satisfactory comparisons of different periods can be made it seems necessary to correct the observed results for differences in the proportion of time spent standing and lying.

#### HEAT EMITTED BY RADIATION AND CONDUCTION.

In previous experiments the basis for such a correction has been obtained by computing the average rate per minute at which heat was brought out of the calorimeter in the water current, either for the entire time spent standing and lying, respectively, or with the omission of such relatively short periods as appeared of little value. In the present experiments a somewhat different plan has been followed. From the records of the rate of flow of water through the heat-absorber system and the observed temperatures of the in-going and outgoing water, the rate per minute at which heat was being brought out was computed at intervals of 4 minutes[1] and the results plotted. Figure 16, representing one of the periods of the experiments of 1907, is a typical example of the results obtained. After a study of these diagrams, those portions of the curves which seemed free from irregularities due to the change from the standing to the lying position, or vice versa, and to the accompanying change in the rate of water flow, and which also seemed fairly free from accidental irregularities, were selected and the average rate per minute at which heat was being given off by radiation and conduction and taken up by the absorber system in the calorimeter computed from these portions of the experiments. In figure 16 the portions selected in that particular subperiod are indicated. In computing the heat during each section of the experiment, the small corrections for capacity and lag, described in Part III, page 208, have been made and consequently the results may be taken to represent, without sensible error, the amounts of heat given off by radiation and conduction to the heat-absorber system during those sections. The table following shows the amounts of heat thus measured.

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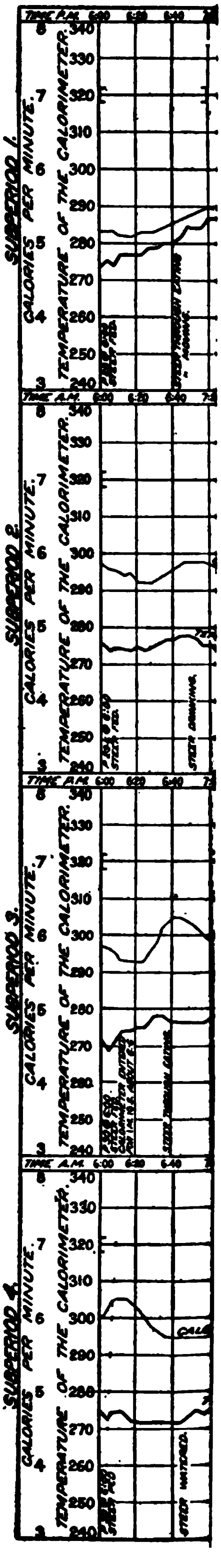
[1] Each rate was in reality the average for 12 minutes, the successive averages overlapping each other.


SUBPERIOD 1.
SUBPERIOD 2.
SUBPERIOD 3.
SUBPERIOD 4.
CALORIES PER MINUTE.
TEMPERATURE OF THE CALORIMETER.
TIME P.M. 6:00 6:20 6:40
TIME A.M. 6:00 6:20 6:40
3
4
5
6
7
8
240
250
260
270
280
290
300
310
320
330
340

92946°—B

TABLE 97.—*Heat emitted by radiation and conduction during periods of standing and lying, 1905.*

| Time. | Standing. | | Lying. | |
|---|---|---|---|---|
| | Elapsed time. | Total heat. | Elapsed time. | Total heat. |
| *Period I.* | | | | |
| Steer A: | *Minutes.* | *Calories.* | *Minutes.* | *Calories.* |
| 6.00 p. m. to 9.04 p. m. | 184 | 813.88 | | |
| 12.00 p. m. to 6.00 a. m. | 360 | 1,299.90 | | |
| 6.00 a. m. to 12.56 p. m. | 416 | 1,548.68 | | |
| 1.16 p. m. to 3.24 p. m. | | | 128 | 326.67 |
| 4.40 p. m. to 6.00 p. m. | 80 | 324.78 | | |
| 6.00 p. m. to 8.40 p. m. | 160 | 617.07 | | |
| 9.12 p. m. to 10.00 p. m. | | | 48 | 135.76 |
| 10.48 p. m. to 11.28 p. m. | | | 40 | 121.21 |
| 12.40 a. m. to 1.28 a. m. | 48 | 203.33 | | |
| 5.00 a. m. to 6.00 a. m. | 60 | 235.99 | | |
| 6.00 a. m. to 7.56 a. m. | 116 | 398.51 | | |
| 9.48 a. m. to 11.56 a. m. | 128 | 470.78 | | |
| 12.16 p. m. to 1.40 p. m. | | | 84 | 181.65 |
| 3.04 p. m. to 6.00 p. m. | 176 | 689.35 | | |
| Totals | 1,728 | 6,602.27 | 300 | 765.29 |
| Correction for feed, water, excreta, etc. | | +9.06 | | |
| | | 6,611.33 | | 765.29 |
| Heat per minute | | 3.8260 | | 2.5509 |
| Steer B: | | | | |
| 6.00 p. m. to 9.40 p. m. | 220 | 920.08 | | |
| 9.44 p. m. to 10.52 p. m. | 68 | | | |
| 11.16 p. m. to 12.04 a. m. | | | 48 | 1,067.66 |
| 12.08 a. m. to 2.44 a. m. | | | 156 | |
| 2.48 a. m. to 5.56 a. m. | | | 188 | |
| 6.00 a. m. to 7.40 a. m. | | | 100 | 274.76 |
| 8.16 a. m. to 9.56 a. m. | 100 | 339.39 | | |
| 1.20 p. m. to 3.52 p. m. | 152 | 477.44 | | |
| 6.12 p. m. to 1.12 a. m. | 420 | 1,575.74 | | |
| 1.48 a. m. to 3.32 a. m. | | | 104 | 603.15 |
| 3.36 a. m. to 4.16 a. m. | | | 40 | |
| 4.20 a. m. to 5.28 a. m. | | | 68 | |
| 5.32 a. m. to 5.56 a. m. | | | 24 | |
| 6.40 a. m. to 9.12 a. m. | 152 | 1,926.44 | | |
| 9.16 a. m. to 9.36 a. m. | 20 | | | |
| 9.40 a. m. to 4.04 p. m. | 384 | | | |
| 4.28 p. m. to 5.56 p. m. | | | 88 | 201.52 |
| Totals | 1,516 | 5,239.09 | 816 | 2,147.09 |
| Correction for feed, water, excreta, etc. | | +21.30 | | +1.68 |
| | | 5,260.39 | | 2,148.77 |
| Heat per minute | | 3.4699 | | 2.6333 |
| *Period II.* | | | | |
| Steer A: | | | | |
| 8.00 p. m. to 8.00 a. m. | 720 | 3,093.01 | | |
| 8.00 a. m. to 11.28 a. m. | 208 | 786.02 | | |
| 6.00 p. m. to 8.00 p. m. | 120 | 538.93 | | |
| 8.00 p. m. to 11.48 p. m. | 228 | 1,034.96 | | |
| 12.12 p. m. to 1.48 p. m. | | | 96 | 302.28 |
| 4.04 p. m. to 5.00 p. m. | | | 56 | 168.61 |
| 4.28 a. m. to 8.00 a. m. | 212 | 912.54 | | |
| 8.00 a. m. to 10.12 a. m. | 132 | 479.33 | | |
| 11.08 a. m. to 12.16 p. m. | | | 68 | 219.38 |
| 12.44 p. m. to 3.12 p. m. | 148 | 669.26 | | |
| 3.32 p. m. to 4.24 p. m. | | | 52 | 150.40 |
| 4.44 p. m. to 6.04 p. m. | 80 | 350.51 | | |
| 6.36 p. m. to 8.00 p. m. | 84 | 347.96 | | |
| Totals | 1,932 | 8,212.52 | 272 | 840.67 |
| Correction for feed, water, excreta, etc. | | +22.28 | | |
| | | 8,234 80 | | 840.67 |
| Heat per minute | | 4.2623 | | 3.0906 |
| Steer B: | | | | |
| 6.44 p. m. to 8.00 p. m. | 76 | 290.98 | | |
| 8.24 p. m. to 11.20 p. m. | | | 176 | 964.25 |
| 11.24 p. m. to 1.52 a. m. | | | 148 | |
| 2.12 a. m. to 5.56 a. m. | 224 | 953.35 | | |

TABLE 97.—*Heat emitted by radiation and conduction during periods of standing and lying, 1905*—Continued.

| Time. | Standing. | | Lying. | |
|---|---|---|---|---|
| | Elapsed time. | Total heat. | Elapsed time. | Total heat. |
| *Period II*—Contiuued. | | | | |
| Steer B—Continued. | *Minutes.* | *Calories.* | *Minutes.* | *Calories.* |
| 8.16 a. m. to 9.56 a. m. | | | 100 | 329.12 |
| 10.32 a. m. to 11.16 a. m. | | | 44 | 134.43 |
| 11.36 a. m. to 12.28 p. m. | 52 | 225.53 | | |
| 12.44 p. m. to 1.36 p. m. | | | 52 | 782.43 |
| 1.40 p. m. to 4.56 p. m. | | | 196 | |
| 5.28 p. m. to 5.56 p. m. | 28 | 131.65 | | |
| 6.00 p. m. to 8.04 p. m. | 124 | 517.06 | | |
| 8.48 p. m. to 9.32 p. m. | | | 44 | 808.93 |
| 9.36 p. m. to 1.08 a. m. | | | 212 | |
| 1.32 a. m. to 4.24 a. m. | 172 | 759.89 | | |
| 4.52 a. m. to 5.28 a. m. | | | 36 | 97.62 |
| 5.48 a. m. to 5.56 a. m. | 8 | 30.28 | | |
| 6.00 a. m. to 9.00 a. m. | 180 | 727.92 | | |
| 9.28 a. m. to 3.40 p. m. | | | 372 | 1,179.29 |
| 4.04 p. m. to 6.00 p. m. | 116 | 486.57 | | |
| Totals | 980 | 4,123.23 | 1,380 | 4,294.07 |
| Correction for feed, water, excreta, etc. | | +23.41 | | |
| | | 4,146.64 | | 4,294.07 |
| Heat per minute | | 4.2313 | | 3.1116 |
| *Period III.* | | | | |
| Steer A: | | | | |
| 10.16 p. m. to 2.36 a. m. | 260 | 945.51 | | |
| 6.08 a. m. to 8.04 a. m. | 116 | 408.94 | | |
| 9.20 a. m. to 11.12 a. m. | 112 | 405.71 | | |
| 12.20 p. m. to 1.28 p. m. | | | 68 | 164.40 |
| 1.40 p. m. to 2.43 p. m. | 63 | 949.11 | | |
| 2.43 p. m. to 6.00 p. m. | 197 | | | |
| 6.00 p. m. to 8.51 p. m. | 171 | 768.30 | | |
| 8.51 p. m. to 9.28 p. m. | 37 | | | |
| 10.04 p. m. to 11.56 p. m. | | | 112 | 277.70 |
| 12.16 a. m. to 12.50 a. m. | 34 | 654.85 | | |
| 12.50 a. m. to 1.07 a. m. | 17 | | | |
| 1.07 a. m. to 3.08 a. m. | 121 | | | |
| 3.28 a. m. to 3.31 a. m. | | | 3 | 302.37 |
| 3.31 a. m. to 4.34 a. m. | | | 63 | |
| 4.34 a. m. to 5.36 a. m. | | | 62 | |
| 6.00 a. m. to 6.42 a. m. | 42 | 936.94 | | |
| 6.42 a. m. to 8.12 a. m. | 90 | | | |
| 8.12 a. m. to 10.32 a. m. | 140 | | | |
| 11.52 a. m. to 12.32 p. m. | | | 40 | 96.91 |
| 1.12 p. m. to 6.00 p. m. | 288 | 999.21 | | |
| Totals | 1,688 | 6,068.57 | 348 | 841.38 |
| Correction for feed, water, excreta, etc. | | −14.07 | | |
| | | 6,054.50 | | 841.38 |
| Heat per minute | | 3.5867 | | 2.4177 |
| Steer B: | | | | |
| 8.00 p. m. to 10.52 p. m. | 172 | 1,184.95 | | |
| 10.56 p. m. to 11.16 p. m. | 20 | | | |
| 11.20 p. m. to 11.44 p. m. | 24 | | | |
| 11.48 p. m. to 1.40 a. m. | 112 | | | |
| 4.24 a. m. to 4.56 a. m. | | | 32 | 199.72 |
| 5.00 a. m. to 5.48 a. m. | | | 48 | |
| 6.08 a. m. to 7.08 a. m. | 60 | 1,026.36 | | |
| 7.12 a. m. to 7.36 a. m. | 24 | | | |
| 7.40 a. m. to 8.08 a. m. | 28 | | | |
| 8.12 a. m. to 11.40 a. m. | 208 | | | |
| 12.16 p. m. to 12.48 p. m. | | | 32 | 299.38 |
| 12.52 p. m. to 12.56 p. m. | | | 4 | |
| 1.00 p. m. to 1.44 p. m. | | | 44 | |
| 1.48 p. m. to 2.40 p. m. | | | 52 | |
| 3.24 p. m. to 5.56 p. m. | 152 | 459.83 | | |
| 6.00 p. m. to 7.24 p. m. | 84 | 254.40 | | |
| 7.48 p. m. to 11.40 p. m. | | | 232 | 533.82 |
| 12.00 p. m. to 1.20 a. m. | 80 | 274.83 | | |
| 1.44 a. m. to 4.44 a. m. | | | 180 | 438.68 |
| 5.00 a. m. to 5.56 a. m. | 52 | 184.37 | | |

TABLE 97.—*Heat emitted by radiation and conduction during periods of standing and lying, 1905*—Continued.

| Time. | Standing. | | Lying. | |
|---|---|---|---|---|
| | Elapsed time. | Total heat. | Elapsed time. | Total heat. |
| *Period III*—Continued. | | | | |
| Steer B—Continued. | *Minutes.* | *Calories.* | *Minutes.* | *Calories.* |
| 6.00 a. m. to 7.04 a. m | 64 | 638.89 | | |
| 7.08 a. m. to 9.32 a. m | 144 | | | |
| 9.56 a. m. to 10.16 a. m | | | 20 | 34.83 |
| 10.44 a. m. to 12.00 a. m | 76 | 240.50 | | |
| 12.20 p. m. to 3.12 p. m | | | 172 | 495.01 |
| 3.16 p. m. to 4.20 p. m | | | 64 | |
| 4.48 p. m. to 6.00 p. m | 72 | 238.81 | | |
| Totals | 1,372 | 4,502.94 | 888 | 2,001.44 |
| Correction for feed, water, excreta, etc | | −23.06 | | |
| | | 4,479.88 | | 2,001.44 |
| Heat per minute | | 3.2652 | | 2.2744 |
| *Period IV.* | | | | |
| Steer A: | | | | |
| 6.00 p. m. to 12.28 a. m | 388 | 1,636.75 | | |
| 12.48 a. m. to 1.36 a. m | | | 48 | 137.63 |
| 1.56 a. m. to 6.00 a. m | 244 | 994.57 | | |
| 6.00 a. m. to 11.16 a. m | 316 | 1,220.41 | | |
| 11.36 a. m. to 12.00 p. m | | | 24 | 146.51 |
| 12.24 p. m. to 6.00 p. m | 336 | 1,317.86 | | |
| 6.00 p. m. to 11.44 p. m | 344 | 1,415.22 | | |
| 12.08 a. m. to 2.28 a. m | | | 140 | 377.75 |
| 2.44 a. m. to 6.00 a. m | 196 | 834.57 | | |
| 6.00 a. m. to 8.36 a. m | 156 | 577.53 | | |
| 9.00 a. m. to 10.40 a. m | | | 100 | 260.96 |
| 11.00 a. m. to 12.04 p. m | 64 | 270.31 | | |
| 2.04 p. m. to 2.36 p. m | 32 | 130.99 | | |
| 3.08 p. m. to 4.08 p. m | 60 | 239.33 | | |
| 4.48 p. m. to 6.00 p. m | 72 | 283.28 | | |
| Totals | 2,208 | 8,920.82 | 312 | 922.85 |
| Correction for feed, water, excreta, etc | | −20.26 | | |
| | | 8,900.56 | | 922.85 |
| Heat per minute | | 4.0310 | | 2.9578 |
| Steer B: | | | | |
| 6.00 p. m. to 6.56 p. m | 56 | 195.27 | | |
| 11.40 p. m. to 5.40 a. m | | | 360 | 963.61 |
| 6.04 a. m. to 8.28 a. m | 144 | 556.33 | | |
| 9.12 a. m. to 12.52 p. m | | | 220 | 556.53 |
| 1.40 p. m. to 3.12 p. m | | | 92 | 644.32 |
| 3.16 p. m. to 4.00 p. m | | | 44 | |
| 4.04 p. m. to 5.56 p. m | | | 112 | |
| 6.00 p. m. to 7.04 p. m | | | 64 | 329.07 |
| 7.08 p. m. to 8.00 p. m | | | 52 | |
| 9.00 p. m. to 10.04 p. m | 64 | 430.23 | | |
| 10.08 p. m. to 10.28 p. m | 20 | | | |
| 10.32 p. m. to 11.08 p. m | 36 | | | |
| 11.36 p. m. to 11.56 p. m | | | 20 | 910.29 |
| 12.00 p. m. to 12.24 a. m | | | 24 | |
| 12.28 a. m. to 1.36 a. m | | | 68 | |
| 1.40 a. m. to 1.48 a. m | | | 8 | |
| 1.52 a. m. to 2.16 a. m | | | 24 | |
| 2.20 a. m. to 5.36 a. m | | | 196 | |
| 6.04 a. m. to 7.12 a. m | 68 | 250.77 | | |
| 7.40 a. m. to 8.24 a. m | | | 44 | 760.78 |
| 8.28 a. m. to 8.56 a. m | | | 28 | |
| 9.00 a. m. to 12.52 p. m | | | 232 | |
| 1.12 p. m. to 2.16 p. m | 64 | 571.72 | | |
| 2.20 p. m. to 4.08 p. m | 108 | | | |
| 4.36 p. m. to 6.00 p. m | | | 84 | 180.20 |
| Totals | 560 | 2,004.32 | 1,672 | 4,344.80 |
| Correction for feed, water, excreta, etc | | −11.51 | | +2.16 |
| | | 1,992.81 | | 4,346.96 |
| Heat per minute | | 3.5586 | | 2.5999 |

The average rate per minute at which heat was given off by radiation and conduction in the standing and lying portions of the several periods is summarized in the following table:

TABLE 98.—*Average heat per minute emitted by radiation and conduction, 1905.*

| Periods. | Standing. | Lying. |
|---|---|---|
| *Steer A.* | *Calories.* | *Calories.* |
| I | 3.8260 | 2.5509 |
| II | 4.2623 | 3.0906 |
| III | 3.5867 | 2.4177 |
| IV | 4.0310 | 2.9578 |
| *Steer B.* | | |
| I | 3.4699 | 2.6333 |
| II | 4.2313 | 3.1116 |
| III | 3.2652 | 2.2744 |
| IV | 3.5586 | 2.5999 |

## HEAT GIVEN OFF AS LATENT HEAT OF WATER VAPOR.

The foregoing table shows the rate at which the animals gave off heat by radiation and conduction when standing and lying, respectively. Unfortunately no such detailed record of the rate at which heat was emitted as latent heat of water vapor is available, since only the total water vapor given off in each subperiod was determined. For the manner in which this was distributed between the standing and lying periods we must therefore depend upon estimates. As was pointed out in a previous paper,[1] the extremes of probable variation would seem to be represented by the assumptions, first, that the heat given off as latent heat of water vapor was proportional to the amount of heat given off by radiation and conduction, or, second, that the total amount given off as latent heat of water vapor was unchanged in the lying as compared with the standing periods. In considering which of these assumptions seems the more probable, it is desirable to anticipate some of the results of the experiments of the two succeeding years.

Table 99 shows the amount of time spent standing and lying in each subperiod of the three series of experiments, the time being expressed both as minutes and as a percentage of the total time, and likewise the percentage of the total heat emitted in each subperiod which was carried off as latent heat of water vapor.

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[1] Bureau of Animal Industry Bul. 51, p. 38.

TABLE 99.—*Percentage of heat emitted as latent heat of water vapor.*

| Periods. | Experiments of 1905. | | | Experiments of 1906. | | | Experiments of 1907. | | |
|---|---|---|---|---|---|---|---|---|---|
| | Time standing. | | Per cent heat in water vapor. | Time standing. | | Per cent heat in water vapor. | Time standing. | | Per cent heat in water vapor. |
| | Minutes. | Per cent. | | Minutes. | Per cent. | | Minutes. | Per cent. | |
| *Steer A.* | | | | | | | | | |
| Period I: | | | | | | | | | |
| Subperiod 1 | 720 | 100.00 | 39.54 | 437 | 60.70 | 23.05 | 402 | 55.84 | 20.92 |
| Subperiod 2 | 571 | 79.31 | 40.69 | 526 | 73.06 | 21.78 | 354 | 49.17 | 21.52 |
| Subperiod 3 | 414 | 57.51 | 37.88 | 223 | 30.97 | 23.11 | 346 | 48.04 | 22.28 |
| Subperiod 4 | 569 | 79.03 | 36.32 | 324 | 45.00 | 21.30 | 349 | 48.48 | 22.12 |
| Totals and averages | 2,274 | 78.96 | 38.70 | 1,510 | 52.43 | 22.32 | 1,451 | 50.38 | 21.72 |
| Period II: | | | | | | | | | |
| Subperiod 1 | 720 | 100.00 | 32.92 | 434 | 60.28 | 26.74 | 417 | 57.92 | 28.98 |
| Subperiod 2 | 468 | 65.01 | 35.85 | 440 | 61.12 | 25.46 | 394 | 54.73 | 29.58 |
| Subperiod 3 | 568 | 78.89 | 36.66 | 429 | 59.58 | 27.17 | 617 | 85.70 | 29.07 |
| Subperiod 4 | 519 | 72.09 | 38.69 | 361 | 50.14 | 26.65 | 425 | 59.03 | 29.16 |
| Totals and averages | 2,275 | 78.99 | 36.04 | 1,664 | 57.78 | 26.49 | 1,853 | 64.34 | 29.19 |
| Period III: | | | | | | | | | |
| Subperiod 1 | 580 | 80.56 | 25.42 | 351 | 48.75 | 20.49 | 444 | 61.67 | 22.05 |
| Subperiod 2 | 583 | 80.98 | 23.44 | 537 | 74.58 | 18.39 | 398 | 55.28 | 22.04 |
| Subperiod 3 | 414 | 57.51 | 22.72 | 349 | 48.48 | 19.27 | 264 | 36.67 | 21.41 |
| Subperiod 4 | 597 | 82.92 | 23.07 | 408 | 56.67 | 19.16 | 308 | 42.78 | 21.92 |
| Totals and averages | 2,174 | 75.49 | 23.70 | 1,645 | 57.12 | 19.32 | 1,414 | 49.10 | 21.85 |
| Period IV: | | | | | | | | | |
| Subperiod 1 | 648 | 90.00 | 25.60 | 337 | 46.81 | 21.78 | 334 | 46.39 | 24.71 |
| Subperiod 2 | 679 | 94.31 | 26.00 | 336 | 46.67 | 21.57 | 435 | 60.42 | 23.83 |
| Subperiod 3 | 551 | 76.53 | 24.64 | 409 | 56.81 | 23.10 | 375 | 52.09 | 24.32 |
| Subperiod 4 | 459 | 63.75 | 26.35 | 382 | 53.06 | 22.19 | 266 | 36.95 | 25.16 |
| Totals and averages | 2,337 | 81.15 | 25.64 | 1,464 | 50.83 | 22.19 | 1,410 | 48.96 | 24.50 |
| *Steer B.* | | | | | | | | | |
| Period I: | | | | | | | | | |
| Subperiod 1 | 294 | 40.84 | 29.48 | 376 | 52.23 | 25.05 | 262 | 36.39 | 22.66 |
| Subperiod 2 | 515 | 71.53 | 32.14 | 344 | 47.78 | 26.91 | 455 | 63.20 | 22.65 |
| Subperiod 3 | 437 | 60.70 | 31.31 | 188 | 26.11 | 24.76 | 304 | 42.22 | 22.61 |
| Subperiod 4 | 621 | 86.25 | 30.01 | 454 | 63.06 | 24.65 | 359 | 49.86 | 22.43 |
| Totals and averages | 1,867 | 64.83 | 30.75 | 1,362 | 47.29 | 25.32 | 1,380 | 47.92 | 22.59 |
| Period II: | | | | | | | | | |
| Subperiod 1 | 357 | 49.58 | 19.75 | 305 | 42.36 | 24.04 | 332 | 46.12 | 31.21 |
| Subperiod 2 | 276 | 38.34 | 26.10 | 337 | 46.81 | 23.56 | 317 | 44.03 | 31.55 |
| Subperiod 3 | 375 | 52.09 | 25.62 | 321 | 44.59 | 22.66 | 301 | 41.81 | 32.43 |
| Subperiod 4 | 322 | 44.72 | 27.11 | 340 | 47.22 | 23.86 | 367 | 50.98 | 32.06 |
| Totals and averages | 1,330 | 46.18 | 24.44 | 1,303 | 45.24 | 23.53 | 1,317 | 45.73 | 31.82 |
| Period III: | | | | | | | | | |
| Subperiod 1 | 467 | 64.87 | 16.70 | 362 | 50.28 | 21.86 | 270 | 37.50 | 26.19 |
| Subperiod 2 | 543 | 75.42 | 20.29 | 483 | 67.09 | 20.28 | 388 | 40.00 | 26.01 |
| Subperiod 3 | 257 | 35.70 | 20.72 | 390 | 54.17 | 20.38 | 200 | 27.78 | 26.64 |
| Subperiod 4 | 401 | 55.70 | 21.02 | 399 | 55.42 | 19.68 | 379 | 52.64 | 26.01 |
| Totals and averages | 1,668 | 57.92 | 19.53 | 1,634 | 56.74 | 20.56 | 1,237 | 42.95 | 26.22 |
| Period IV: | | | | | | | | | |
| Subperiod 1 | 156 | 21.67 | 28.96 | 249 | 34.58 | 21.39 | 277 | 38.48 | 27.58 |
| Subperiod 2 | 190 | 26.39 | 24.64 | 217 | 30.14 | 19.80 | 302 | 41.95 | 27.31 |
| Subperiod 3 | 194 | 26.94 | 26.97 | 211 | 29.31 | 20.73 | 253 | 35.14 | 30.21 |
| Subperiod 4 | 267 | 37.08 | 28.67 | 275 | 38.20 | 22.52 | 301 | 41.81 | 31.67 |
| Totals and averages | 807 | 28.02 | 27.28 | 952 | 33.05 | 21.12 | 1,133 | 39.34 | 29.20 |

If the absolute amount of heat given off as latent heat of water vapor is independent of whether the animal is standing or lying, then in any subperiod in which the percentage time spent standing is greater than the average for the entire period, a larger percentage of the total heat would tend to be given off by radiation and conduction, and a less proportion would appear as latent heat of water vapor. If, on the other hand, the heat given off as latent heat of water vapor is proportional to the heat given off by radiation and conduction, then the ratio between the two would be unaffected by the standing or lying of the animal.

The amount of heat carried off in the water vapor is also influenced, however, by the relative humidity of the ventilating air current and by its temperature, and these effects might mask the effect of the standing and lying in a single experiment. The foregoing table, however, allows of 96 such comparisons, the results of which are as follows:

Out of 46 subperiods in which the percentage of time spent standing was greater than the average for the period, there were 23 cases in which the heat carried off in the water vapor was above the average for the period and 23 in which it was below the average for the period.

Out of 50 subperiods in which the percentage of time spent standing was less than the average for the period, there were 25 cases in which the heat carried off in the water vapor was above the average for the period and 25 in which it was below the average for the period.

In other words, the above figures give no indication of any influence of the standing and lying positions upon the proportions of heat eliminated as latent heat of water vapor and by radiation and conduction, respectively. An entirely similar result may be obtained by similar comparisons of the results of the experiments upon timothy hay reported in Bulletin 51 of this bureau.

Averaging the percentage of total heat brought out in the water vapor in the foregoing 46 and 50 subperiods, respectively, we obtain the following averages:

*Percentage of heat as latent heat of water vapor.*

| | Per cent. |
|---|---|
| Time spent standing greater than average | 25.73 |
| Time spent standing less than average | 25.46 |

The foregoing seems to justify the conclusion that the percentage of the heat which is given off as latent heat of water vapor is independent of the standing or lying of the animal and that at any rate a correction of the observed heat production based upon this assumption will probably not involve any serious error. The method of computing the correction to a uniform number of hours of standing and lying has already been described and illustrated in Part I, page 43.

### HEAT PRODUCTION CORRECTED TO 12 HOURS' STANDING.

With the exception of the experiments with steer A in 1905, the time spent standing does not vary widely from 12 hours out of the 24, averaging 710 minutes. It will be convenient, therefore, to correct the heat emission to 12 hours' standing, which will make the correction relatively small in most of the experiments. Applying to the several periods the methods of computation illustrated in Part I, and adding the same correction as in Table 90 for the gain or loss of matter by the body, we have the following results for the heat production corrected to 12 hours' standing:

TABLE 100.—*Heat production corrected to 12 hours' standing, 1905.*

| Periods. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Corrected total heat emission. | Correction for gain or loss of matter by body. | Corrected total heat production. | Corrected total heat emission. | Correction for gain or loss of matter by body. | Corrected total heat production. |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| I | 7,644.8 | +93.9 | 7,738.7 | 6,231.8 | +130.7 | 6,362.5 |
| II | 8,474.2 | −89.4 | 8,384.8 | 7,451.7 | − 43.1 | 7,408.6 |
| III | 5,692.1 | −56.3 | 5,635.8 | 5,116.3 | − 35.6 | 5,080.7 |
| IV | 6,778.1 | −69.1 | 6,709.0 | 5,996.7 | −145.0 | 5,851.7 |

### AVAILABILITY OF METABOLIZABLE ENERGY.

By substituting the foregoing corrected values for the heat production in the energy balances of Table 91, we obtain the corresponding corrected values for the gain or loss of energy by the body of the animal. These can then be compared with the amounts of metabolizable energy supplied in the feed. In the foregoing tables the energy value of the growth of hair and brushings has been given separately. In previous publications this has been treated as part of the gain by the body, but in strictness it should not be thus regarded. The growth of hair and other epidermal tissue goes on substantially independent of the feed supply, except possibly in extreme cases, and is more analogous to an excretum than to a gain of tissue. In the following comparisons "Gain" signifies only the actual increase of protein and fat, exclusive of the growth of hair, etc.

TABLE 101.—*Corrected gains*[1] *of energy by the animals, 1905.*

| Periods. | Steer A. | | Steer B. | |
|---|---|---|---|---|
| | Income. | Outgo. | Income. | Outgo. |
| *Period I.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Metabolizable | 6,889.1 | | 5,647.5 | |
| Brushings and hair | | 101.7 | | 86.9 |
| Heat (from Table 100) | | 7,738.7 | | 6,362.5 |
| Gain | 951.3 | | 801.9 | |
| Total | 7,840.4 | 7,840.4 | 6.449.4 | 6,449.4 |
| *Period II.* | | | | |
| Metabolizable | 10,044.4 | | 7,816.6 | |
| Brushings and hair | | 101.7 | | 86.9 |
| Heat (from Table 100) | | 8,384.8 | | 7,408.6 |
| Gain | | 1,557.9 | | 321.1 |
| Total | 10,044.4 | 10,044.4 | 7,816.6 | 7.816.6 |
| *Period III.* | | | | |
| Metabolizable | 3,641.4 | | 3,042.9 | |
| Brushings and hair | | 101.7 | | 86.9 |
| Heat (from Table 100) | | 5,635.8 | | 5,080.7 |
| Gain | 2,096.1 | | 2,124.7 | |
| Total | 5.737.5 | 5,737.5 | 5,167.6 | 5,167.6 |
| *Period IV.* | | | | |
| Metabolizable | 6,115.3 | | 4,897.7 | |
| Brushings and hair | | 101.7 | | 86.9 |
| Heat (from Table 100) | | 6,709.0 | | 5,851.7 |
| Gain | 695.4 | | 1,040.9 | |
| Total | 6,810.7 | 6,810.7 | 5,938.6 | 5.938.6 |

[1] A gain entered under the heading "Income" is, of course, a negative gain, i. e., a loss.

While the gain or loss of energy by the animal might, of course, be compared with the total energy supplied in the feed, it is in many respects preferable to compare it with the metabolizable energy. In this way the relation is made more independent of accidental variations in the excretion of feces, urine, and methane. Thus, for example, if the excretion of feces in a given period be in error by the equivalent of 100 calories, the metabolizable energy and the gain of energy by the animal are both affected by an equal amount and in the same direction, so that the relation between the two is relatively less affected than is that between the gain and the total energy of the feed. Moreover, the comparison with the metabolizable energy would seem to afford a more rational comparison of the physiological processes of nutrition proper.

The average live weights of the animals for the last six weighings of each period were as follows:

TABLE 102.—*Average live weights in calorimeter experiments, 1905.*

| Periods. | Steer A. | Steer B. |
|---|---|---|
| | *Kilos.* | *Kilos.* |
| I | 270.7 | 198.6 |
| II | 279.1 | 196.9 |
| III | 268.8 | 194.1 |
| IV | 277.5 | 189.6 |

### TIMOTHY HAY.

A comparison of Periods III and IV shows the availability of the metabolizable energy of the hay. Correcting for the differences in live weight by means of the formula in Part I (p. 44), in which $m$ = the percentage availability, we have:

TABLE 103.—*Availability of metabolizable energy of timothy hay, 1905.*

| Steer A—Periods IV-III. | Steer B—Periods IV-III. |
|---|---|
| $n=\left(\frac{268.8}{277.5}\right)^{2/3}=0.9{,}781$<br>$x_3=3{,}641.4 \quad y_3=-2{,}096.1$<br>$x_4=6{,}115.3 \quad y_4=-\ 695.4$<br>$m=\frac{-2{,}096.1-(0.9781\times-\ 695.4)}{3{,}641.4-(0.9781\times\ 6{,}115.3)}=60.51$ per cent. | $n=\left(\frac{194.1}{189.6}\right)^{2/3}=1.016$<br>$x_3=3{,}042.9 \quad y_3=-2{,}124.7$<br>$x_4=4{,}897.7 \quad y_4=-1{,}040.9$<br>$m=\frac{-2{,}124.7-(1.016\times-1{,}040.9)}{3{,}042.9-(1.016\times\ 4{,}897.7)}=55.21$ per cent. |

### WHEAT BRAN.

In Periods I and II two different amounts of wheat bran were added to the basal ration of Period III. By comparing either Period I or II with Period III, or by comparing Periods I and II with each other, we have the basis on which to compute the availability of the metabolizable energy of the bran. Before this can be done, however, a small correction must be made, in the manner described in Part I (p. 45), for the differences in the amounts of hay consumed. The following table contains these corrections computed on the basis of the results for the average metabolizable energy of the hay per gram of organic matter contained in Table 94 and those for the percentage availability of the latter contained in Table 103. In these computations each animal is considered separately.

TABLE 104.—*Corrections for differences in amount of hay eaten, 1905.*

| Periods. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Organic matter of hay. | Metabolizable energy of total rations. | Gain by animal. | Organic matter of hay. | Metabolizable energy of total rations. | Gain by animal. |
| | *Grams.* | *Calories.* | *Calories.* | *Grams.* | *Calories.* | *Calories.* |
| Period III | 1,919.6 | | | 1,698.4 | | |
| Period I | 1,894.3 | 6,889.1 | −951.3 | 1,643.2 | 5,647.5 | −801.9 |
| Correction | 25.3 | 46.9 | 28.4 | 55.2 | 104.3 | + 57.6 |
| Period I corrected | 1,919.6 | 6,936.0 | −922.9 | 1,698.4 | 5,751.8 | −744.3 |
| Period III | 1,919.6 | | | 1,698.4 | | |
| Period II | 1,910.8 | 10,044.4 | +1,557.9 | 1,697.2 | 7,816.6 | +321.1 |
| Correction | 8.8 | 16.3 | 9.9 | 1.2 | 2.3 | 1.3 |
| Period II corrected | 1,919.6 | 10,060.7 | +1,567.8 | 1,698.4 | 7,818.9 | +322.4 |

Using these corrected figures for Periods I and II, the computations of availability are as follows:

TABLE 105.—*Availability of metabolizable energy of wheat bran, 1905.*

| Steer A.—Periods I-III. | Steer B.—Periods I-III. |
|---|---|
| $n=\left(\frac{268.8}{270.7}\right)^{2/3}=0.9951$<br>$x_3=3,641.4 \quad y_3=-2,096.1$<br>$x_1=6,936.0 \quad y_1=-\ 922.9$<br>$m=\frac{-2,096.1-(0.9951\times -922.9)}{3,641.4-(0.9951\times 6,936.0)}=36.11$ per cent. | $n=\left(\frac{194.1}{198.6}\right)^{2/3}=0.9847$<br>$x_3=3,042.9 \quad y_3=-2,124.7$<br>$x_1=5,751.8 \quad y_1=-\ 744.3$<br>$m=\frac{-2,124.7-(0.9847\times -744.3)}{3,043.9-(0.9847\times 5,751.8)}=53.10$ per cent. |
| **Steer A.—Periods II-III.** | **Steer B.—Periods II-III.** |
| $n=\left(\frac{268.8}{279.1}\right)^{2/3}=0.9752$<br>$x_3=3,641.4 \quad y_3=-2,096.1$<br>$x_2=10,060.7 \quad y_2=1,567.8$<br>$m=\frac{-2,096.1-(0.9752\times 1,567.8)}{3,641.4-(0.9752\times 10,060.7)}=58.74$ per cent. | $n=\left(\frac{194.1}{196.9}\right)^{2/3}=0.9,904$<br>$x_3=3,042.9 \quad y_3=-2,124.7$<br>$x_2=7,818.9 \quad y_2=322.4$<br>$m=\frac{-2,124.7-(0.9904\times 322.4)}{3,042.9-(0.9904\times 7,818.9)}=51.98$ per cent. |
| **Steer A.—Periods II-I.** | **Steer B.—Periods II-I.** |
| $n=\left(\frac{270.7}{279.1}\right)^{2/3}=0.9797$<br>$x_1=6,936.0 \quad y_1=-\ 922.9$<br>$x_2=10,060.7 \quad y_2=1,567.8$<br>$m=\frac{-\ 922.9-(0.9797\times 1,567.8)}{6,936.0-(0.9797\times 10,060.7)}=84.18$ per cent. | $n=\left(\frac{198.6}{196.9}\right)^{2/3}=1.006$<br>$x_1=5,751.8 \quad y_1=-744.3$<br>$x_2=7,818.9 \quad y_2=322.4$<br>$m=\frac{-\ 744.3-(1.006\times 322.4)}{5,751.8-(1.006\times 7,818.9)}=50.55$ per cent. |

The results of this series are summarized in Table 106 and represented graphically in figure 7 on page 47, where the abscissas represent the metabolizable energy of the feed and the ordinates the gain or loss by the body of the animal. The diagram includes the corrections for the hay and for the differences in live weight.

TABLE 106.—*Summary of percentage availability of metabolizable energy, 1905.*

| | Steer A. | Steer B. |
|---|---|---|
| Timothy hay: | *Per cent.* | *Per cent.* |
| Periods III and IV | 60.51 | 55.21 |
| Wheat bran: | | |
| Periods II and III | 58.74 | 51.98 |
| Periods I and III | 36.11 | 53.10 |
| Periods I and II | 84.18 | 50.55 |

## RESPIRATION CALORIMETER EXPERIMENTS OF 1906.

Beginning on December 4, 1905, the attempt was made to repeat the experiments of 1905 upon wheat bran and timothy hay. The animals, however, showed the same distaste for the exclusive bran ration as in the previous year and in view of the experience of that year it was thought better on the whole to abandon the attempt and to use in the calorimeter experiments the same grain mixture which was employed in the general feeding.

## FEEDING STUFFS.

*Hay.*—The hay used was from the same crop as that employed during the previous year, and, although it had been stored for more than 12 months, was in excellent condition. It was nearly pure timothy containing very little red clover. Somewhat less than 1,000 kilograms was run through the feed cutter on December 12, 1905. Duplicate samples were taken as in the previous year, and the remainder was stored in the same loft previously used. The composition of the two samples taken at this time, as well as of those subsequently taken when the rations were weighed out for the several periods, was as shown in the following table. It will be observed that the two general samples agree very closely in composition. Those taken later show a somewhat higher percentage of nitrogen, with the exception of that in Period III, and also rather more crude fiber, but the differences hardly seem sufficient to seriously disturb the comparison of the periods. That the hay differed considerably in composition from that of the previous year may have been due to variations in quality in different parts of the mow, or possibly to greater losses in handling in the experiments of 1905.

TABLE 107.—*Composition of dry matter of timothy hay, 1906.*

| Components. | General samples. | | | Samples taken during experiments— | | | |
|---|---|---|---|---|---|---|---|
| | A. | B. | Average. | Period I. | Period II. | Period III. | Period IV. |
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Ash | 5.87 | 5.85 | 5.86 | 5.71 | 5.45 | 5.82 | 5.87 |
| Protein[1] | 6.69 | 6.74 | 6.72 | 7.52 | 7.28 | 7.11 | 7.58 |
| Nonprotein[1] | .84 | .81 | .83 | .56 | .75 | .50 | .66 |
| Crude fiber | 33.29 | 32.76 | 33.02 | 34.46 | 33.29 | 34.06 | 34.10 |
| Nitrogen-free extract | 50.65 | 51.38 | 51.01 | 49.07 | 50.68 | 50.73 | 49.82 |
| Ether extract | 2.66 | 2.46 | 2.56 | 2.68 | 2.55 | 1.78 | 1.97 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Total nitrogen | 1.250 | 1.252 | 1.251 | 1.324 | 1.325 | 1.245 | 1.354 |
| Protein nitrogen | 1.071 | 1.079 | 1.075 | 1.204 | 1.165 | 1.138 | 1.213 |
| Carbon | .......... | .......... | .......... | 46.52 | 46.65 | 47.32 | 46.72 |
| Hydrogen | .......... | .......... | .......... | 7.02 | 6.39 | 6.52 | 6.35 |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Energy—per gram | 4.5669 | 4.4548 | 4.5159 | 4.4831 | 4.4837 | 4.5098 | 4.5090 |

[1] Computed from nitrogen, using the factors stated in Part III, page 203.

*Grain.*—The grain consisted of a mixture of one part of bran, three of corn meal, and three of old-process linseed meal by weight. The required daily amount of each grain was weighed out separately and each day's ration mixed before feeding, samples of the individual grains being taken at the same time, the analyses of which are contained in the table following.

TABLE 108.—*Composition of dry matter of grain, 1906.*

| Components. | Wheat bran. | | Corn meal. | | Linseed meal. | |
|---|---|---|---|---|---|---|
| | Period I. | Period II. | Period I. | Period II. | Period I. | Period II. |
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Ash | [1] 6.90 | 6.93 | 1.53 | 1.50 | 5.72 | 5.79 |
| Protein[2] | 15.01 | 13.43 | 9.17 | 9.23 | 26.21 | 25.09 |
| Nonprotein[2] | 2.29 | 2.95 | 1.11 | .15 | 6.79 | 6.21 |
| Crude fiber | 9.40 | 9.80 | 2.11 | 2.16 | 8.76 | 9.01 |
| Nitrogen-free extract | 61.64 | 62.16 | 80.83 | 81.69 | 43.88 | 45.82 |
| Ether extract | 4.76 | 4.73 | 5.25 | 5.27 | 8.64 | 8.08 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Total nitrogen | 3.121 | 2.984 | 1.765 | 1.571 | 6.210 | 5.884 |
| Protein nitrogen | 2.634 | 2.356 | 1.529 | 1.539 | 4.766 | 4.562 |
| Carbon | 45.02 | 45.54 | 45.90 | 46.25 | 48.18 | 48.16 |
| Hydrogen | 6.94 | 6.91 | 7.04 | 7.13 | 6.84 | 6.88 |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Energy—per gram | 4.5435 | 4.5136 | 4.5229 | 4.5260 | 4.9088 | 4.9117 |

[1] Calculated from composite sample.

[2] Computed from nitrogen, using the factors stated in Part III, page 203.

As the grains were being weighed out, an additional portion of the mixed grain was prepared and an analysis made of this as a check upon the results of the single analyses. Table 109 shows the composition of these composite samples as compared with the composition computed from the weights and composition of individual grains, the results showing a very satisfactory agreement.

TABLE 109.—*Composition of dry matter of mixed grain, 1906.*

| Components. | Period I. | | Period II. | |
|---|---|---|---|---|
| | Computed. | Composite sample. | Computed. | Composite sample. |
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Ash | 4.09 | 4.22 | 4.11 | 4.23 |
| Protein[1] | 17.31 | 16.91 | 16.63 | 17.09 |
| Nonprotein[1] | 3.71 | 3.65 | 3.15 | 3.75 |
| Crude fiber | 6.00 | 6.49 | 6.19 | 6.57 |
| Nitrogen-free extract | 62.26 | 62.11 | 63.52 | 62.72 |
| Ether extract | 6.63 | 6.62 | 6.40 | 5.64 |
| | 100.00 | 100.00 | 100.00 | 100.00 |
| Total nitrogen | 3.864 | 3.720 | 3.621 | 3.773 |
| Protein nitrogen | 3.074 | 2.944 | 2.951 | 2.976 |
| Carbon | 46.75 | 46.51 | 46.97 | 47.20 |
| Hydrogen | 6.94 | 6.94 | 6.99 | 6.86 |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Energy per gram | 4.6912 | 4.6925 | 4.6895 | 4.7079 |

[2] Computed from nitrogen, using the factors stated in Part III, page 203.

## PERIODS AND RATIONS.

Beginning December 4, 1905, the grain feed of the steers, which up to that time had been the mixture of bran, corn meal, and linseed meal used in the general feeding, was gradually changed to bran alone, which was fed December 17 to 22, inclusive. As already stated, it was not well relished by the animals, the amounts eaten were small, and no gain in weight was made. Accordingly, a return was made to the mixed-grain feed, the experimental periods beginning January 7 for steer A and January 14 for steer B. The dates of the periods and the rations given were as follows, the dates being inclusive, as in previous experiments, and a day signifying the 24 hours ending at 6 p. m. on the date named:

TABLE 110.—*Periods, 1906.*

| Periods. | Steer A. | | Steer B. | |
|---|---|---|---|---|
| | Preliminary feeding. | Excreta collected. | Preliminary feeding. | Excreta collected. |
| I | Jan. 7 to 17 | Jan. 18 to 27 | Jan. 14 to 24 | Jan. 25 to Feb. 2. |
| Transition feeding[1] | Jan 28 to Feb. 3 | | Feb. 4 to 10 | |
| II | Feb. 4 to 14 | Feb. 15 to 24 | Feb. 11 to 22 | Feb. 23 to Mar. 3. |
| III | Feb. 25 to Mar. 7 | Mar. 8 to 17 | Mar. 4 to 14 | Mar. 15 to 24 |
| IV | Mar. 18 to 28 | Mar. 29 to Apr. 7 | Mar. 25 to Apr. 4 | Apr. 5 to 14. |

[1] Amount of grain gradually increased.

TABLE 111.—*Daily rations, 1906.*

| Periods. | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Timothy hay. | Wheat bran. | Corn meal. | Linseed meal. | Timothy hay. | Wheat bran. | Corn meal. | Linseed meal. |
| | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| I | 3,000 | 300 | 900 | 900 | 2,800 | 200 | 600 | 600 |
| II | 3,000 | 700 | 2,100 | 2,100 | 2,800 | 357 | 1,072 | 1,071 |
| III | 3,000 | | | | 2,800 | | | |
| IV | 5,000 | | | | 4,300 | | | |

## DIGESTIBILITY OF THE RATIONS.

The experimental methods were the same as those of the previous year. From the data in Tables VII and VIII of the appendix, the digestibility of the rations is computed in Tables 112 to 119.

TABLE 112.—*Feed and excreta—Period I, 1906.*

| | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of days. | Fresh weight. | Dry matter. | | Number of days. | Fresh weight. | Dry matter. | |
| | | *Grams.* | *Per cent.* | *Grams.* | | *Grams.* | *Per cent.* | *Grams.* |
| Timothy hay: | | | | | | | | |
| Total | 10 | 30,000.0 | 86.95 | 26,085.0 | 9 | 25,200.0 | 86.95 | 21,911.4 |
| Uneaten | ........ | 5.8 | 96.58 | 5.6 | ........ | 16.0 | 84.38 | 13.5 |
| Eaten | ........ | 29,994.2 | .......... | 26,079.4 | ........ | 25,184.0 | .......... | 21,897.9 |
| Eaten per day | ........ | 2,999.4 | .......... | 2,607.9 | ........ | 2,798.2 | .......... | 2,433.1 |
| Wheat bran: | | | | | | | | |
| Total | 10 | 3,000.0 | 86.59 | 2,597.7 | 9 | 1,800.0 | 86.59 | 1,558.6 |
| Eaten per day | ........ | 300.0 | .......... | 259.8 | ........ | 200.0 | .......... | 173.2 |
| Corn meal: | | | | | | | | |
| Total | 10 | 9,000.0 | 81.66 | 7,349.4 | 9 | 5,400.0 | 81.66 | 4,409.6 |
| Eaten per day | ........ | 900.0 | .......... | 734.9 | ........ | 600.0 | .......... | 490.0 |
| Linseed meal: | | | | | | | | |
| Total | 10 | 9,000.0 | 88.59 | 7,973.1 | 9 | 5,400.0 | 88.59 | 4,783.9 |
| Eaten per day | ........ | 900.0 | .......... | 797.3 | ........ | 600.0 | .......... | 531.5 |
| Feces: | | | | | | | | |
| Collected | 10 | 77,372.0 | 18.88 | 14,607.8 | 9 | 50,305.0 | 22.50 | 11,318.6 |
| Spilled, Jan. 24 | ........ | .......... | .......... | 1.0 | ........ | .......... | .......... | .......... |
| Spilled, Jan. 31 | ........ | .......... | .......... | .......... | ........ | 7.2 | 87.98 | 6.3 |
| In duct | ........ | 187.8 | 22.63 | 42.5 | ........ | 20.0 | 63.06 | 12.6 |
| Total | ........ | 77,559.8 | .......... | 14,651.3 | ........ | 50,332.2 | .......... | 11,337.5 |
| Excreted per day | ........ | 7,756.0 | .......... | 1,465.1 | ........ | 5,592.4 | .......... | 1,259.7 |

TABLE 113.—*Digestibility of rations—Period I, 1906.*

| | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Carbon. | Hydrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Steer A.*** | *Grams.* | *Gms.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Gms.* | *Calories.* |
| Timothy hay | 2,607.9 | 148.9 | 2,459.0 | 196.1 | 14.6 | 898.7 | 1,279.7 | 69.9 | 34.5 | 1,213.2 | 183.1 | 11,691.5 |
| Wheat bran | 259.8 | [1] 17.9 | 241.9 | 39.0 | 5.9 | 24.4 | 160.1 | 12.4 | 8.1 | 117.0 | 18.0 | 1,180.4 |
| Corn meal | 734.9 | 11.2 | 723.7 | 67.4 | 8.2 | 15.5 | 594.0 | 38.6 | 13.0 | 337.3 | 51.7 | 3,323.9 |
| Linseed meal | 797.3 | 45.6 | 751.7 | 209.0 | 54.1 | 69.8 | 349.9 | 68.9 | 49.5 | 384.1 | 54.5 | 3,913.8 |
| Total | 4,399.9 | 223.6 | 4,176.3 | 511.5 | 82.8 | 1,008.4 | 2,383.7 | 189.8 | 105.1 | 2,051.6 | 307.3 | 20,109.6 |
| Feces | 1,465.1 | 138.7 | 1,326.4 | 195.7 | ...... | 456.4 | 643.2 | 31.1 | 31.3 | 699.9 | 93.5 | 6,855.6 |
| Digested | 2,934.8 | 84.9 | 2,849.9 | 315.8 | 82.8 | 552.0 | 1,740.5 | 158.7 | 73.8 | 1,351.7 | 213.8 | 13,254.0 |
| Percentage digestibility | 66.70 | 37.97 | 68.24 | 61.74 | 100.00 | 54.74 | 73.02 | 83.61 | 70.22 | 65.89 | 69.56 | 65.91 |
| ***Steer B.*** | | | | | | | | | | | | |
| Timothy hay | 2,433.1 | 138.9 | 2,294.2 | 183.0 | 13.6 | 838.4 | 1,193.9 | 65.2 | 32.2 | 1,131.9 | 170.8 | 10,907.8 |
| Wheat bran | 173.2 | [1] 12.0 | 161.2 | 26.0 | 4.0 | 16.3 | 106.7 | 8.2 | 5.4 | 78.0 | 12.0 | 786.9 |
| Corn meal | 490.0 | 7.5 | 482.5 | 44.9 | 5.4 | 10.3 | 396.1 | 25.7 | 8.6 | 224.9 | 34.5 | 2,216.2 |
| Linseed meal | 531.5 | 30.4 | 501.1 | 139.3 | 36.1 | 46.6 | 233.2 | 45.9 | 33.0 | 256.1 | 36.4 | 2,609.0 |
| Total | 3,627.8 | 188.8 | 3,439.0 | 393.2 | 59.1 | 911.6 | 1,929.9 | 145.0 | 79.2 | 1,690.9 | 253.7 | 16,519.9 |
| Feces | 1,259.7 | 114.4 | 1,145.3 | 157.1 | ...... | 408.1 | 553.5 | 26.6 | 25.2 | 606.7 | 79.9 | 5,930.0 |
| Digested | 2,368.1 | 74.4 | 2,293.7 | 236.1 | 59.1 | 503.5 | 1,376.4 | 118.4 | 54.0 | 1,084.2 | 173.8 | 10,589.9 |
| Percentage digestibility | 65.28 | 39.41 | 66.70 | 60.05 | 100.00 | 55.23 | 71.32 | 81.66 | 68.18 | 64.12 | 68.51 | 64.10 |

[1] Estimated.

TABLE 114.—*Feed and excreta—Period II, 1906.*

| | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of days. | Fresh weight. | Dry matter. | | Number of days. | Fresh weight. | Dry matter. | |
| Timothy hay: | | *Grams.* | *Per cent.* | *Grams.* | | *Grams.* | *Per cent.* | *Grams.* |
| Total | 10 | 30,000.0 | 87.76 | 26,328.0 | 9 | 25,200.0 | 87.76 | 22,115.5 |
| Uneaten | | 19.5 | 96.41 | 18.8 | | 31.2 | 96.15 | 30.0 |
| Eaten | | 29,980.5 | | 26,309.2 | | 25,168.8 | | 22,085.5 |
| Eaten per day | | 2,998.1 | | 2,630.9 | | 2,796.5 | | 2,453.9 |
| Wheat bran: | | | | | | | | |
| Total | 10 | 7,000.0 | 85.20 | 5,964.0 | 9 | 3,213.0 | 85.20 | 2,737.5 |
| Eaten per day | | 700.0 | | 596.4 | | 357.0 | | 304.2 |
| Corn meal: | | | | | | | | |
| Total | 10 | 21,000.0 | 82.54 | 17,333.4 | 9 | 9,468.0 | 82.54 | 7,963.5 |
| Eaten per day | | 2,100.0 | | 1,733.3 | | 1,072.0 | | 884.8 |
| Linseed meal: | | | | | | | | |
| Total | 10 | 21,000.0 | 87.76 | 18,429.6 | 9 | 9,639.0 | 87.77 | 8,460.2 |
| Eaten per day | | 2,100.0 | | 1,843.0 | | 1,071.0 | | 940.0 |
| Feces: | | | | | | | | |
| Collected | 10 | 139,310.0 | 15.43 | 21,495.5 | 9 | 79,250.0 | 18.18 | 14,407.7 |
| In duct | | 1,193.5 | 17.12 | 204.3 | | 574.2 | 20.44 | 117.4 |
| Spilled, Feb. 15 | | 27.5 | 33.09 | 9.1 | | | | |
| Spilled, Feb. 18 | | 6.0 | 75.00 | 4.5 | | | | |
| Spilled, Feb. 20 | | 33.5 | 45.67 | 15.3 | | | | |
| Spilled, Feb. 23 | | 16.8 | 84.85 | 14.3 | | | | |
| Spilled, Mar. 1 | | | | | | 10.0 | 52.00 | 5.2 |
| Total | | 140,587.3 | | 21,743.0 | | 79,834.2 | | 14,530.3 |
| Excreted per day | | 14,058.7 | | 2,174.3 | | 8,870.5 | | 1,614.5 |

TABLE 115.—*Digestibility of rations—Period II, 1906.*

| | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Carbon. | Hydrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Steer A.* | *Grams.* | *Gms.* | *Grams.* | *Gms.* | *Gms.* | *Gms.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Gms.* | *Calories.* |
| Timothy hay | 2,630.9 | 143.4 | 2,487.5 | 191.5 | 19.7 | 875.8 | 1,333.3 | 67.1 | 34.9 | 1,227.3 | 168.1 | 11,796.2 |
| Wheat bran | 596.4 | 41.3 | 555.1 | 80.1 | 17.6 | 58.4 | 370.7 | 28.2 | 17.8 | 271.6 | 41.2 | 2,691.9 |
| Corn meal | 1,733.3 | 26.0 | 1,707.3 | 160.0 | 2.6 | 37.4 | 1,415.9 | 91.3 | 27.2 | 801.7 | 123.6 | 7,844.7 |
| Linseed meal | 1,843.2 | 106.7 | 1,736.5 | 462.4 | 114.5 | 166.1 | 844.5 | 148.9 | 108.4 | 887.6 | 126.8 | 9,052.3 |
| Total | 6,803.8 | 317.4 | 6,486.4 | 894.0 | 154.4 | 1,137.7 | 3,964.4 | 335.5 | 188.3 | 3,188.2 | 459.7 | 31,385.1 |
| Feces | 2,174.3 | 184.8 | 1,989.5 | 363.5 | | 694.7 | 883.4 | 47.8 | 58.2 | 1,045.8 | 145.0 | 10,196.6 |
| Digested | 4,629.5 | 132.6 | 4,496.9 | 530.5 | 154.4 | 443.0 | 3,081.0 | 287.7 | 130.1 | 2,142.4 | 314.7 | 21,188.5 |
| Percentage digestibility | 68.04 | 41.78 | 69.33 | 59.34 | 100.00 | 38.94 | 77.72 | 85.75 | 69.09 | 67.20 | 68.46 | 67.51 |
| *Steer B.* | | | | | | | | | | | | |
| Timothy hay | 2,453.9 | 133.7 | 2,320.2 | 178.6 | 18.4 | 816.9 | 1,243.6 | 62.6 | 32.5 | 1,144.7 | 156.8 | 11,002.6 |
| Wheat bran | 304.2 | 21.1 | 283.1 | 40.8 | 9.0 | 29.8 | 189.1 | 14.4 | 9.1 | 138.5 | 21.0 | 1,373.0 |
| Corn meal | 884.8 | 13.3 | 871.5 | 81.7 | 1.3 | 19.1 | 722.8 | 46.6 | 13.9 | 409.2 | 63.1 | 4,004.6 |
| Linseed meal | 940.0 | 54.4 | 885.6 | 235.8 | 58.4 | 84.7 | 430.7 | 76.0 | 55.3 | 452.7 | 64.7 | 4,617.0 |
| Total | 4,582.9 | 222.5 | 4,360.4 | 536.9 | 87.1 | 950.5 | 2,586.2 | 199.6 | 110.8 | 2,145.1 | 305.6 | 20,997.2 |
| Feces | 1,614.5 | 139.0 | 1,475.5 | 218.8 | | 563.6 | 661.0 | 32.1 | 35.0 | 769.6 | 105.7 | 7,476.3 |
| Digested | 2,968.4 | 83.5 | 2,884.9 | 318.1 | 87.1 | 386.9 | 1,925.2 | 167.5 | 75.8 | 1,375.5 | 199.9 | 13,520.9 |
| Percentage digestibility | 64.77 | 37.53 | 66.16 | 59.25 | 100.00 | 40.70 | 74.44 | 83.92 | 68.41 | 64.12 | 65.41 | 64.39 |

TABLE 116.—*Feed and excreta—Period III, 1906.*

| | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of days. | Fresh weight. | Dry matter. | | Number of days. | Fresh weight. | Dry matter. | |
| Timothy hay: | | *Grams.* | *Per cent.* | *Grams.* | | *Grams.* | *Per cent.* | *Grams.* |
| Total | 10 | 30,000.0 | 88.25 | 26,475.0 | 10 | 28,000.0 | 88.25 | 24,710.0 |
| Uneaten | | | | 3.4 | | | | 7.2 |
| Eaten | | | | 26,471.6 | | | | 24,702.8 |
| Eaten per day | | | | 2,647.2 | | | | 2,470.3 |
| Feces: | | | | | | | | |
| Collected | 10 | 54,980.0 | 21.77 | 11,969.1 | 10 | 46,545.0 | 23.12 | 10,761.2 |
| Spilled, Mar. 15 | | 11.3 | 91.15 | 10.3 | | | | |
| In duct | | 39.2 | 27.30 | 10.7 | | | | 3.3 |
| Washed from duct | | | | 1.1 | | | | 4.3 |
| Total | | 55,030.5 | | 11,991.2 | | 46,545.0 | | 10,768.8 |
| Excreted per day | | 5,503.1 | | 1,199.1 | | 4,654.5 | | 1,076.9 |

TABLE 117.—*Digestibility of rations—Period III, 1906.*

| | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Carbon. | Hydrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Steer A.* | *Grams.* | *Gms.* | *Grams.* | *Gms.* | *Grams.* | *Gms.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Gms.* | *Calories.* |
| Timothy hay | 2,647.2 | 154.1 | 2,493.1 | 188.2 | 13.2 | 901.6 | 1,342.9 | 47.1 | 33.0 | 1,252.7 | 172.6 | 11,938.3 |
| Feces | 1,199.1 | 79.1 | 1,120.0 | 128.4 | | 415.0 | 551.8 | 24.7 | 20.5 | 589.2 | 78.5 | 5,757.0 |
| Digested | 1,448.1 | 75.0 | 1,373.1 | 59.8 | 13.2 | 486.6 | 791.1 | 22.4 | 12.5 | 663.5 | 94.1 | 6,181.3 |
| Percentage digestibility | 54.70 | 48.67 | 55.08 | 31.77 | 100.00 | 53.97 | 58.91 | 47.56 | 37.88 | 52.97 | 54.52 | 51.78 |
| *Steer B.* | | | | | | | | | | | | |
| Timothy hay | 2,470.3 | 143.8 | 2,326.5 | 175.6 | 12.4 | 841.4 | 1,253.2 | 44.0 | 30.8 | 1,169.0 | 161.1 | 11,140.6 |
| Feces | 1,076.9 | 83.0 | 993.9 | 113.7 | | 351.5 | 503.8 | 24.9 | 18.2 | 533.0 | 71.1 | 5,168.3 |
| Digested | 1,393.4 | 60.8 | 1,332.6 | 61.9 | 12.4 | 489.9 | 749.4 | 19.1 | 12.6 | 636.0 | 90.0 | 5,972.3 |
| Percentage digestibility | 56.41 | 42.28 | 57.28 | 35.25 | 100.00 | 58.22 | 59.80 | 43.41 | 40.91 | 54.41 | 55.87 | 53.61 |

TABLE 118.—*Feed and excreta—Period IV, 1906.*

| | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of days. | Fresh weight. | Dry matter. | | Number of days. | Fresh weight. | Dry matter. | |
| Timothy hay: | | *Grams.* | *Per cent.* | *Grams.* | | *Grams.* | *Per cent.* | *Grams.* |
| Total | 10 | 50,000.0 | 88.49 | 44,245.0 | 10 | 43,000.0 | 88.49 | 38,050.7 |
| Eaten per day | | 5,000.0 | | 4,424.5 | | 4,300.0 | | 3,805.1 |
| Feces: | | | | | | | | |
| Collected | 10 | 109,865.0 | 18.86 | 20,720.5 | 10 | 83,585.0 | 20.44 | 17,084.8 |
| Spilled, Mar. 13 | | | | | | 26.5 | 50.94 | 13.5 |
| In duct | | 170.3 | 17.92 | 30.5 | | 93.7 | 86.31 | 80.9 |
| Total | | 110,035.3 | | 20,751.0 | | 83,705.2 | | 17,179.2 |
| Excreted per day | | 11,003.5 | | 2,075.1 | | 8,370.5 | | 1,717.9 |

TABLE 119.—*Digestibility of rations—Period IV, 1906.*

| | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Carbon. | Hydrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Steer A.*** | *Grams.* | *Gms.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Gms.* | *Calories.* |
| Timothy hay.. | 4,424.5 | 259.7 | 4,164.8 | 335.4 | 29.2 | 1,508.8 | 2,204.3 | 87.2 | 59.9 | 2,067.1 | 281.0 | 19,950.2 |
| Feces.......... | 2,075.1 | 148.4 | 1,926.7 | 216.6 | ...... | 723.4 | 942.3 | 44.4 | 34.7 | 1,013.9 | 131.4 | 9,957.4 |
| Digested...... | 2,349.4 | 111.3 | 2,238.1 | 118.8 | 29.2 | 785.4 | 1,262.0 | 42.8 | 25.2 | 1,053.2 | 149.6 | 9,992.8 |
| Percentage digestibility... | 53.10 | 42.86 | 53.74 | 35.42 | 100.00 | 52.05 | 57.25 | 49.08 | 42.07 | 50.95 | 53.24 | 50.09 |
| ***Steer B.*** | | | | | | | | | | | | |
| Timothy hay.. | 3,805.1 | 223.4 | 3,581.7 | 288.4 | 25.1 | 1,297.5 | 1,895.7 | 75.0 | 51.5 | 1,777.7 | 241.6 | 17,157.3 |
| Feces.......... | 1,717.9 | 128.0 | 1,589.9 | 184.3 | ...... | 575.5 | 794.4 | 35.7 | 29.5 | 851.2 | 115.6 | 8,235.7 |
| Digested...... | 2,087.2 | 95.4 | 1,991.8 | 104.1 | 25.1 | 722.0 | 1,101.3 | 39.3 | 22.0 | 926.5 | 126.0 | 8,921.6 |
| Percentage digestibility... | 54.85 | 42.70 | 55.61 | 36.10 | 100.00 | 55.65 | 58.09 | 52.40 | 42.72 | 52.12 | 52.15 | 52.00 |

## DIGESTIBILITY OF TIMOTHY HAY AND OF MIXED GRAIN.

The average digestibility of the timothy hay in Periods III and IV, computed as in the experiments of the previous year, i. e., giving weight to each period in proportion to the amount of hay eaten, is shown in Table 120, while Table 121 contains the computation of the digestibility of the mixed grain.

TABLE 120.—*Average digestibility of timothy hay, 1906.*

| | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Carbon. | Hydrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Steer A.*** | *Grams.* | *Gms.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Gms.* | *Calories.* |
| **Fed in Period III..........** | 2,647.2 | 154.1 | 2,493.1 | 188.2 | 13.2 | 901.6 | 1,342.9 | 47.1 | 33.0 | 1,252.7 | 172.6 | 11,938.3 |
| **Fed in Period IV..........** | 4,424.5 | 259.7 | 4,164.8 | 335.4 | 29.2 | 1,508.8 | 2,204.3 | 87.2 | 59.9 | 2,067.1 | 281.0 | 19,950.2 |
| **Total...** | 7,071.7 | 413.8 | 6,657.9 | 523.6 | 42.4 | 2,410.4 | 3,547.2 | 134.3 | 92.9 | 3,319.8 | 453.6 | 31,888.5 |
| **Digested in Period III...** | 1,448.1 | 75.0 | 1,373.1 | 59.8 | 13.2 | 486.6 | 791.1 | 22.4 | 12.5 | 663.5 | 94.1 | 6,181.3 |
| **Digested in Period IV...** | 2,349.4 | 111.3 | 2,238.1 | 118.8 | 29.2 | 785.4 | 1,262.0 | 42.8 | 25.2 | 1,053.2 | 149.6 | 9,992.8 |
| **Total...** | 3,797.5 | 186.3 | 3,611.2 | 178.6 | 42.4 | 1,272.0 | 2,053.1 | 65.2 | 37.7 | 1,716.7 | 243.7 | 16,174.1 |
| **Percentage digestibility...** | 53.70 | 45.02 | 54.24 | 34.11 | 100.00 | 52.77 | 57.88 | 48.55 | 40.58 | 51.71 | 53.73 | 50.72 |
| ***Steer B.*** | | | | | | | | | | | | |
| **Fed in Period III..........** | 2,470.3 | 143.8 | 2,326.5 | 175.6 | 12.4 | 841.4 | 1,253.2 | 44.0 | 30.8 | 1,169.0 | 161.1 | 11,140.6 |
| **Fed in Period IV..........** | 3,805.1 | 223.4 | 3,581.7 | 288.4 | 25.1 | 1,297.5 | 1,895.7 | 75.0 | 51.5 | 1,777.7 | 241.6 | 17,157.3 |
| **Total...** | 6,275.4 | 367.2 | 5,908.2 | 464.0 | 37.5 | 2,138.9 | 3,148.9 | 119.0 | 82.3 | 2,946.7 | 402.7 | 28,297.9 |
| **Digested in Period III...** | 1,393.4 | 60.8 | 1,332.6 | 61.9 | 12.4 | 489.9 | 749.4 | 19.1 | 12.6 | 636.0 | 90.0 | 5,972.3 |
| **Digested in Period IV...** | 2,087.2 | 95.4 | 1,991.8 | 104.1 | 25.1 | 722.0 | 1,101.3 | 39.3 | 22.0 | 926.5 | 126.0 | 8,921.6 |
| **Total...** | 3,480.6 | 156.2 | 3,324.4 | 166.0 | 37.5 | 1,211.9 | 1,850.7 | 58.4 | 34.6 | 1,562.5 | 216.0 | 14,893.9 |
| **Percentage digestibility...** | 55.46 | 42.54 | 56.27 | 35.78 | 100.00 | 56.66 | 58.77 | 49.08 | 42.04 | 53.03 | 53.64 | 52.63 |

TABLE 121.—*Computed digestibility of mixed grain, 1906.*

|  | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Carbon. | Hydrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Steer A.* |  |  |  |  |  |  |  |  |  |  |  |  |
| Period I: |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *Grams.* | *Gms.* | *Grams.* | *Gms.* | *Gms.* | *Gms.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Gms.* | *Calories.* |
| Total digested.... | 2,934.8 | 84.9 | 2,849.9 | 315.8 | 82.8 | 552.0 | 1,740.5 | 158.7 | 73.8 | 1,351.7 | 213.8 | 13,254.0 |
| Computed digestible in hay.... | 1,400.4 | 67.0 | 1,333.8 | 66.9 | 14.6 | 474.2 | 740.7 | 33.9 | 14.0 | 627.3 | 98.4 | 5,929.9 |
| Digested from grain... | 1,534.4 | 17.9 | 1,516.1 | 248.9 | 68.2 | 77.8 | 999.8 | 124.8 | 59.8 | 724.4 | 115.4 | 7,324.1 |
| Total in grain..... | 1,792.0 | 74.7 | 1,717.3 | 315.4 | 68.2 | 109.7 | 1,104.0 | 119.9 | 70.6 | 838.4 | 124.2 | 8,418.1 |
| Percentage digestibility.... | 85.63 | 23.96 | 88.28 | 78.92 | 100.00 | 70.92 | 90.56 | 104.09 | 84.70 | 86.40 | 92.91 | 87.00 |
|  |  |  |  |  |  | 88.78 |  |  |  |  |  |  |
| Period II: |  |  |  |  |  |  |  |  |  |  |  |  |
| Total digested.... | 4,629.5 | 132.6 | 4,496.9 | 530.5 | 154.4 | 443.0 | 3,081.0 | 287.7 | 130.1 | 2,142.4 | 314.7 | 21,188.5 |
| Computed digestible in hay.... | 1,412.8 | 64.6 | 1,349.2 | 65.3 | 19.7 | 462.2 | 771.7 | 32.6 | 14.2 | 634.6 | 90.3 | 5,983.0 |
| Digested from grain... | 3,216.7 | 68.0 | 3,147.7 | 465.2 | 134.7 | −19.2 | 2,309.3 | 255.1 | 115.9 | 1,507.8 | 224.4 | 15,205.5 |
| Total in grain..... | 4,172.9 | 174.0 | 3,998.9 | 702.5 | 134.7 | 261.9 | 2,631.1 | 268.4 | 153.4 | 1,960.9 | 291.6 | 19,588.9 |
| Percentage digestibility..... | 77.09 | 39.08 | 78.71 | 66.22 | 100.00 | − 7.33 | 87.77 | 95.04 | 75.55 | 76.89 | 76.95 | 77.62 |
|  |  |  |  |  |  | 79.19 |  |  |  |  |  |  |
| *Steer B.* |  |  |  |  |  |  |  |  |  |  |  |  |
| Period I: |  |  |  |  |  |  |  |  |  |  |  |  |
| Total digested.... | 2,368.1 | 74.4 | 2,293.7 | 236.1 | 59.1 | 503.5 | 1,376.4 | 118.4 | 54.0 | 1,084.2 | 173.8 | 10,589.9 |
| Computed digestible in hay.... | 1,349.4 | 59.1 | 1,290.9 | 65.5 | 13.6 | 475.0 | 701.7 | 32.0 | 13.5 | 600.2 | 91.6 | 5,740.8 |
| Digested from grain... | 1,018.7 | 15.3 | 1,002.8 | 170.6 | 45.5 | 28.5 | 674.7 | 86.4 | 40.5 | 484.0 | 82.2 | 4,849.1 |
| Total in grain..... | 1,194.7 | 49.9 | 1,144.8 | 210.2 | 45.5 | 73.2 | 736.0 | 79.8 | 47.0 | 559.0 | 82.9 | 5,612.1 |
| Percentage digestibility.... | 85.27 | 30.66 | 87.60 | 81.16 | 100.00 | 38.93 | 91.67 | 108.27 | 86.17 | 86.58 | 99.16 | 86.40 |
|  |  |  |  |  |  | 86.91 |  |  |  |  |  |  |
| Period II: |  |  |  |  |  |  |  |  |  |  |  |  |
| Total digested.... | 2,968.4 | 83.5 | 2,884.9 | 318.1 | 87.1 | 386.9 | 1,925.2 | 167.5 | 75.8 | 1,375.5 | 199.9 | 13,520.9 |
| Computed digestible in hay.... | 1,360.9 | 56.9 | 1,305.6 | 63.9 | 18.4 | 462.9 | 730.9 | 30.7 | 13.7 | 607.0 | 84.1 | 5,790.7 |
| Digested from grain... | 1,607.5 | 26.6 | 1,579.3 | 254.2 | 68.7 | −76.0 | 1,194.3 | 136.8 | 62.1 | 768.5 | 115.8 | 7,730.2 |
| Total in grain..... | 2,129.0 | 88.8 | 2,040.2 | 358.3 | 68.7 | 133.6 | 1,342.6 | 137.0 | 78.3 | 1,000.4 | 148.8 | 9,994.6 |
| Percentage digestibility.... | 75.50 | 29.95 | 77.41 | 70.95 | 100.00 | −56.88 | 88.95 | 99.85 | 79.31 | 76.82 | 77.82 | 77.34 |
|  |  |  |  |  |  | 75.76 |  |  |  |  |  |  |

## URINARY EXCRETION.

The urine was collected, sampled, and analyzed in precisely the same way as in the experiment of the previous year, but in addition triplicate determinations of nitrogen were made daily in a sample of the fresh urine. The results of these daily determinations and the daily excretion of nitrogen are recorded in Table VII of the appendix. The result of the nitrogen determination made upon the composite sample for the whole period is likewise recorded in the same table and shows a satisfactory agreement with that computed from the daily analyses. Table 122 contains the results on the urine, which are also summarized in Table 123.

TABLE 122.—*Results on urine (inclusive of wash water), 1906.*

| | Weight. | Average specific gravity. | Total solids. | | Total nitrogen. | | Total carbon. | | Total hydrogen. | | Energy. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Per gram. | Total. |
| *Period I.* | | | | | | | | | | | | |
| Steer A: | *Grams.* | | *P.ct.* | *Gms.* | *P.ct.* | *Gms.* | *P.ct.* | *Grams.* | *P.ct.* | *Gms.* | *Cals.* | *Cals.* |
| Collected........ | 52,615.0 | 1.0410 | 8.310 | 4,372.3 | 1.307 | 687.48 | 1.903 | 1,001.26 | 0.335 | 176.26 | 192.7 | 10,139.4 |
| Spilled, Jan. 21.. | 813.1 | ...... | .032 | .3 | .005 | .04 | [1].007 | .06 | [1].001 | .01 | [1].7 | .6 |
| Spilled, Jan. 27.. | 173.5 | ...... | 9.137 | 15.9 | 1.437 | 2.49 | [1]2.093 | 3.63 | [1].339 | .59 | [1]211.8 | 36.7 |
| Total........ | ........ | ...... | ...... | 4,388.5 | ..... | 690.01 | ...... | 1,004.95 | ..... | 176.86 | ...... | 10,176.7 |
| Average (10 days) | ........ | ...... | ...... | 438.9 | ..... | 69.00 | ...... | 100.50 | ..... | 17.69 | ...... | 1,017.7 |
| Steer B: | | | | | | | | | | | | |
| Collected........ | 27,093.0 | 1.0531 | 11.690 | ....... | 1.828 | 495.26 | 3.004 | 813.87 | .445 | 120.56 | 292.8 | 7,932.5 |
| Average (9 days) | ........ | ...... | ...... | 351.9 | ..... | 55.02 | ...... | 90.43 | ..... | 13.40 | ...... | 881.4 |
| *Period II.* | | | | | | | | | | | | |
| Steer A: | | | | | | | | | | | | |
| Collected........ | 50,815.0 | 1.0408 | 9.270 | ....... | 2.112 | 1,073.39 | 2.529 | 1,285.11 | .448 | 227.65 | 259.4 | 13,180.1 |
| Average (8 days) | ........ | ...... | ...... | 588.8 | ..... | 134.17 | ...... | 160.64 | ..... | 28.46 | ...... | 1,647.5 |
| Steer B: | | | | | | | | | | | | |
| Collected........ | 31,035.0 | 1.0513 | 11.679 | ....... | 2.195 | 681.26 | 3.251 | 1,008.95 | .553 | 171.62 | 319.9 | 9,229.1 |
| Average (9 days) | ........ | ...... | ...... | 402.7 | ..... | 75.70 | ...... | 112.11 | ..... | 19.07 | ...... | 1,103.2 |
| *Period III.* | | | | | | | | | | | | |
| Steer A: | | | | | | | | | | | | |
| Collected........ | 49,805.0 | 1.0315 | 6.521 | ....... | .669 | 333.43 | 1.358 | 676.35 | .194 | 96.62 | 116.1 | 5,781.0 |
| Average (10 days) | ........ | ...... | ...... | 324.8 | ..... | 33.34 | ...... | 67.64 | ..... | 9.66 | ...... | 578.1 |
| Steer B: | | | | | | | | | | | | |
| Collected........ | 25,685.0 | 1.0380 | 8.615 | ....... | .962 | 247.05 | 1.989 | 510.87 | .307 | 78.85 | 187.6 | 4,819.8 |
| Average (9 days) | ........ | ...... | ...... | 245.9 | ..... | 27.45 | ...... | 56.76 | ..... | 8.76 | ...... | 535.5 |
| *Period IV.* | | | | | | | | | | | | |
| Steer A: | | | | | | | | | | | | |
| Collected........ | 44,840.0 | 1.0356 | 7.838 | ....... | .687 | 308.02 | 1.897 | 850.61 | .268 | 120.17 | 163.4 | 7,327.0 |
| Average (10 days) | ........ | ...... | ...... | 351.5 | ..... | 30.80 | ...... | 85.06 | ..... | 12.02 | ...... | 732.7 |
| Steer B: | | | | | | | | | | | | |
| Collected........ | 32,385.0 | 1.0433 | 10.412 | 3,371.9 | .930 | 301.12 | 2.416 | 782.42 | .431 | 139.58 | 217.2 | 7,032.5 |
| Spilled, Apr. 12.. | 157.0 | ...... | 8.252 | 13.0 | .737 | 1.16 | [1]1.915 | 3.01 | [1].281 | .44 | [1]172.1 | 27.0 |
| Total........ | ........ | ...... | ...... | 3,384.9 | ..... | 302.28 | ...... | 785.43 | ..... | 140.02 | ...... | 7,059.5 |
| Average (10 days) | ........ | ...... | ...... | 338.5 | ..... | 30.23 | ...... | 78.54 | ..... | 14.00 | ...... | 706.0 |

[1] Assumed to be proportional to nitrogen content.

TABLE 123.—*Average daily excretion in urine, 1906.*

| Periods. | Nitrogen. | Carbon. | Energy. | Energy per gram of carbon. |
|---|---|---|---|---|
| *Steer A.* | *Grams.* | *Grams.* | *Calories.* | *Calories.* |
| I | 69.00 | 100.50 | 1,017.7 | 10.13 |
| II | 134.17 | 160.64 | 1,647.5 | 10.26 |
| III | 33.34 | 67.64 | 578.1 | 8.55 |
| IV | 30.80 | 85.06 | 732.7 | 8.61 |
| *Steer B.* | | | | |
| I | 55.02 | 90.43 | 881.4 | 9.75 |
| II | 75.70 | 112.11 | 1,103.2 | 9.84 |
| III | 27.45 | 56.76 | 535.5 | 9.43 |
| IV | 30.23 | 78.54 | 706.0 | 8.99 |

## PRODUCTION OF EPIDERMAL TISSUE.

As in the previous year's experiments, the steer was thoroughly brushed before entering and after leaving the calorimeter and the material thus obtained weighed and analyzed. The results of these determinations are contained in Table 124.

TABLE 124.—*Weight and composition of brushings for the two days in the calorimeter, 1906.*

| Components and energy. | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Period I. | Period II. | Period III. | Period IV. | Period I. | Period II. | Period III. | Period IV. |
| Weight.....grams.. | 37.8 | 60.0 | 24.5 | 25.8 | 43.0 | 47.0 | 26.2 | 29.1 |
| Dry matter.....per cent.. | 95.67 | 94.87 | 95.70 | 95.75 | 97.61 | 95.30 | 95.97 | 94.29 |
| Weight of dry matter.....grams.. | 36.16 | 56.92 | 23.45 | 24.70 | 41.97 | 44.79 | 25.14 | 27.44 |
| In dry matter: | | | | | | | | |
| Nitrogen— | | | | | | | | |
| Percentage..... | 4.70 | 4.80 | 4.98 | 5.85 | 4.46 | 4.59 | 7.07 | 5.39 |
| Weight.....grams.. | 1.70 | 2.73 | 1.17 | 1.44 | 1.87 | 2.06 | 1.78 | 1.48 |
| Carbon— | | | | | | | | |
| Percentage..... | 36.72 | 40.48 | 41.56 | 40.76 | 37.89 | 40.96 | 41.74 | 37.90 |
| Weight.....grams.. | 13.28 | 23.04 | 9.75 | 10.07 | 15.90 | 18.35 | 10.49 | 10.40 |
| Hydrogen— | | | | | | | | |
| Percentage..... | 5.14 | 5.49 | 5.63 | 5.79 | 5.06 | 5.52 | 5.94 | 5.20 |
| Weight.....grams.. | 1.86 | 3.12 | 1.32 | 1.43 | 2.12 | 2.47 | 1.49 | 1.43 |
| Energy— | | | | | | | | |
| Per gram.....calories.. | 4.244 | 4.447 | 4.534 | 4.564 | 4.223 | 4.415 | 4.603 | 4.193 |
| Total.....do.... | 153.46 | 253.12 | 106.32 | 112.73 | 177.24 | 197.75 | 115.72 | 115.06 |

The steers were clipped just before the beginning of the experiment, viz, steer A on January 5 and steer B January 11, and were again clipped shortly after the close of the experiment, steer A on April 19 and steer B on April 20. The weights and composition of the hair obtained at this second clipping were as follows:

TABLE 125.—*Weight and composition of hair, 1906.*

| Components and energy. | Steer A. | Steer B. |
|---|---|---|
| Number of days | 104 | 99 |
| Weight ... grams | 554.00 | 289.00 |
| Dry matter ... per cent | 89.40 | 87.11 |
| Weight of dry matter ... grams | 495.28 | 251.75 |
| Dry matter per day ... do | 4.76 | 2.54 |
| In dry matter: | | |
| Nitrogen— | | |
| Percentage | 15.45 | 15.64 |
| Weight ... grams | 76.52 | 39.37 |
| Daily average ... do | .74 | .40 |
| Carbon— | | |
| Percentage | 49.45 | 49.26 |
| Weight ... grams | 244.92 | 124.01 |
| Daily average ... do | 2.36 | 1.25 |
| Hydrogen— | | |
| Percentage | 7.78 | 7.91 |
| Weight ... grams | 38.54 | 19.91 |
| Daily average ... do | .37 | .20 |
| Energy— | | |
| Per gram ... calories | 5,380.00 | 5,391.00 |
| Total ... do | 2,664.61 | 1,357.18 |
| Daily average ... do | 25.62 | 13.71 |

If we may assume that the brushings represent fairly well the average daily loss of hair and epidermis, the sum of the brushings and hair would represent the daily growth of epidermal tissue, exclusive, of course, of that of hoofs and horns. The results as computed are shown in Table 126. They may, perhaps, be regarded as being somewhat too high, since the brushings may exceed the average daily loss, but they may fairly be taken to represent with a sufficient degree of approximation the daily demand of material for this growth.

TABLE 126.—*Average daily production of epidermal tissue, 1906.*

| Components and energy. | Steer A. | Steer B. |
|---|---|---|
| Dry matter ... grams | 22.42 | 19.96 |
| Nitrogen ... do | 1.62 | 1.30 |
| Carbon ... do | 9.38 | 8.14 |
| Hydrogen ... do | 1.34 | 1.14 |
| Energy ... calories | 103.83 | 89.48 |

## DETERMINATION OF RESPIRATORY PRODUCTS.

The methods employed were the same as those of the previous year and the results are tabulated below in the same form. The average ratio of hydrogen to carbon in the hydrocarbon gases excreted was as follows:

TABLE 127.—*Ratio of hydrogen to carbon in combustible gases, 1906.*

| Periods. | Steer A. | Steer B. |
|---|---|---|
| | 1: | 1: |
| I | 3.171 | 3.221 |
| II | 3.171 | 3.345 |
| III | 3.355 | 3.510 |
| IV | [1] 3.212 | 3.191 |

[1] Second day only.

TABLE 128.—*Carbon and hydrogen in gaseous excreta, 1906.*

| | In $CO_2$ and $H_2O$. | | In hydrocarbons. | | $CH_4$ computed from C. | H : C in hydrocarbons. |
|---|---|---|---|---|---|---|
| | Carbon. | Hydrogen. | Carbon. | Hydrogen. | | |
| *Period I.* | | | | | | |
| Steer A, Jan. 24 and 25: | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | 1 : |
| Subperiod 1 | 525.51 | 212.87 | 35.64 | 10.96 | 47.61 | 3.262 |
| Subperiod 2 | 529.95 | 195.20 | 37.59 | 12.06 | 50.22 | 3.117 |
| First day | 1,055.46 | 408.07 | 73.23 | 23.02 | 97.83 | 3.181 |
| Subperiod 3 | 514.35 | 198.94 | 38.21 | 12.02 | 51.04 | 3.179 |
| Subperiod 4 | 519.59 | 184.58 | 41.03 | 13.05 | 54.82 | 3.144 |
| Second day | 1,033.94 | 383.52 | 79.24 | 25.07 | 105.86 | 3.161 |
| Average | 1,044.70 | 395.80 | 76.24 | 24.05 | 101.85 | 3.171 |
| Steer B, Jan. 31 and Feb. 1: | | | | | | |
| Subperiod 1 | 488.21 | 222.56 | 30.69 | 9.62 | 41.00 | 3.190 |
| Subperiod 2 | 491.02 | 217.24 | 29.92 | 9.34 | 39.97 | 3.203 |
| First day | 979.23 | 439.80 | 60.61 | 18.96 | 80.97 | 3.197 |
| Subperiod 3 | 467.92 | 205.46 | 26.60 | 8.15 | 35.54 | 3.264 |
| Subperiod 4 | 494.84 | 208.36 | 23.56 | 7.28 | 31.48 | 3.236 |
| Second day | 962.76 | 413.82 | 50.16 | 15.43 | 67.02 | 3.251 |
| Average | 971.00 | 426.81 | 53.39 | 17.20 | 74.00 | 3.221 |
| *Period II.* | | | | | | |
| Steer A, Feb. 21 and 22: | | | | | | |
| Subperiod 1[1] | 735.05 | 332.42 | 39.10 | 12.46 | 52.24 | 3.138 |
| Subperiod 2 | 760.89 | 308.06 | 35.86 | 11.28 | 47.91 | 3.179 |
| First day | 1,495.94 | 640.48 | 74.96 | 23.74 | 100.15 | 3.158 |
| Subperiod 3 | 754.31 | 342.13 | 30.40 | 9.46 | 40.61 | 3.214 |
| Subperiod 4 | 755.51 | 318.04 | 34.28 | 10.83 | 45.80 | 3.165 |
| Second day | 1,509.82 | 660.17 | 64.68 | 20.29 | 86.41 | 3.188 |
| Average | 1,502.88 | 650.33 | 69.82 | 22.02 | 93.28 | 3.171 |
| Steer B, Feb. 28 and Mar. 1: | | | | | | |
| Subperiod 1 | 540.42 | 224.80 | 23.78 | 7.05 | 31.77 | 3.373 |
| Subperiod 2 | 537.22 | 215.91 | 34.07 | 10.79 | 45.52 | 3.158 |
| First day | 1,077.64 | 440.71 | 57.85 | 17.84 | 77.29 | 3.243 |
| Subperiod 3 | 540.35 | 209.12 | 24.15 | 6.49 | 32.26 | 3.721 |
| Subperiod 4 | 543.87 | 221.98 | 22.98 | 7.05 | 30.70 | 3.260 |
| Second day | 1,084.22 | 431.10 | 47.13 | 13.54 | 62.96 | 3.481 |
| Average | 1,080.93 | 435.91 | 52.49 | 15.69 | 70.13 | 3.345 |
| *Period III.* | | | | | | |
| Steer A, Mar. 14 and 15: | | | | | | |
| Subperiod 1 | 384.19 | 143.33 | 16.72 | 4.83 | 22.34 | 3.462 |
| Subperiod 2 | 385.25 | 131.90 | 16.56 | 4.87 | 22.12 | 3.400 |
| First day | 769.44 | 275.23 | 33.28 | 9.70 | 44.46 | 3.431 |
| Subperiod 3 | 379.44 | 138.11 | 22.30 | 6.80 | 29.79 | 3.279 |
| Subperiod 4 | 379.74 | 134.81 | 21.02 | 6.30 | 28.08 | 3.336 |
| Second day | 759.18 | 272.92 | 43.32 | 13.10 | 57.87 | 3.307 |
| Average | 764.31 | 274.08 | 38.30 | 11.40 | 51.17 | 3.355 |

[1] Uncertain. Power off at intervals.

TABLE 128.—*Carbon and hydrogen in gaseous excreta, 1906*—Continued.

| | In $CO_2$ and $H_2O$. | | In hydrocarbons. | | $CH_4$ computed from C. | H:C in hydrocarbons. |
|---|---|---|---|---|---|---|
| | Carbon. | Hydrogen. | Carbon. | Hydrogen. | | |
| *Period III*—Continued. | | | | | | |
| Steer B, Mar. 21 and 22: | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | 1: |
| Subperiod 1 | 355.06 | 143.24 | 14.77 | 4.17 | 19.73 | 3.542 |
| Subperiod 2 | 352.35 | 129.85 | 16.70 | 5.04 | 22.31 | 3.313 |
| First day | 707.41 | 273.09 | 31.47 | 9.21 | 42.04 | 3.417 |
| Subperiod 3 | 357.40 | 135.63 | 13.27 | 3.59 | 17.73 | 3.696 |
| Subperiod 4 | 349.08 | 126.25 | 14.44 | 4.06 | 19.29 | 3.557 |
| Second day | 706.48 | 261.88 | 27.71 | 7.65 | 37.02 | 3.622 |
| Average | 706.95 | 267.49 | 29.59 | 8.43 | 39.53 | 3.510 |
| *Period IV.* | | | | | | |
| Steer A, Apr. 4 and 5: | | | | | | |
| Subperiod 1 | 450.86 | 166.75 | [15.21] | 4.51 | ........... | ........... |
| Subperiod 2 | 452.41 | 165.06 | 22.30 | 6.84 | 29.79 | 3.260 |
| First day | 903.27 | 331.80 | 37.51 | 11.35 | ........... | ........... |
| Subperiod 3 | 464.51 | 193.30 | 23.09 | 7.05 | 30.85 | 3.275 |
| Subperiod 4 | 460.88 | 172.66 | 32.48 | 10.26 | 43.39 | 3.169 |
| Second day | 925.39 | 365.96 | 55.57 | 17.30 | 74.24 | 3.212 |
| Average | 914.33 | 348.88 | 51.91 | 14.33 | 69.35 | ........... |
| Steer B, Apr. 11 and 12: | | | | | | |
| Subperiod 1 | 408.13 | 153.17 | 25.97 | 7.94 | 34.70 | 3.271 |
| Subperiod 2 | 404.95 | 130.83 | 30.05 | 9.48 | 40.14 | 3.170 |
| First day | 813.08 | 284.00 | 56.02 | 17.42 | 74.84 | 3.216 |
| Subperiod 3 | 412.90 | 150.48 | 30.82 | 9.71 | 41.18 | 3.174 |
| Subperiod 4 | 409.97 | 155.39 | 30.51 | 9.64 | 40.76 | 3.165 |
| Second day | 822.87 | 305.87 | 61.33 | 19.35 | 81.94 | 3.170 |
| Average | 817.98 | 294.94 | 58.68 | 18.39 | 78.39 | 3.191 |

### COMPUTED METHANE PRODUCTION.

In the experiments of 1906 the supply of gas to the furnaces in which the combustible gases produced by the animal were oxidized was inadequate, and it is questionable whether the oxidation was complete. The researches of Kellner have shown that the amount of methane produced bears a fairly constant ratio to the total amount of carbohydrates digested. The following table shows the amount of carbon found in the combustible gases in the experiments of each of the three years, expressed both in grams and as a percentage of the amount of carbohydrates digested. The results for 1906 seem to show very clearly that the methane was irregularly and incompletely oxidized, the ratio of methane carbon to carbohydrate being much lower than in the other series or in Kellner's experiments.

TABLE 129.—*Methane carbon.*

| | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Digested carbohydrates. | Carbon in combustible gases. | Per cent. | Digested carbohydrates. | Carbon in combustible gases. | Per cent. |
| Experiments of 1905: | *Grams.* | *Grams.* | | *Grams.* | *Grams.* | |
| Period I | 1,599.2 | 62.02 | 3.88 | 1,359.9 | 49.31 | 3.63 |
| Period II | 2,222.6 | 79.27 | 3.57 | 1,795.9 | 66.15 | 3.68 |
| Period III | 1,007.5 | 34.70 | 3.44 | 911.5 | 34.06 | 3.74 |
| Period IV | 1,690.9 | 59.30 | 3.51 | 1,351.9 | 44.42 | 3.29 |
| Experiments of 1906: | | | | | | |
| Period I | 2,292.5 | 76.24 | 3.33 | 1,679.9 | 55.39 | 2.95 |
| Period II | 3,524.0 | 69.82 | 1.98 | 2,312.1 | 52.49 | 2.27 |
| Period III | 1,277.7 | 38.30 | 3.00 | 1,239.3 | 29.59 | 2.39 |
| Period IV | 2,047.4 | 51.91 | 2.54 | 1,823.3 | 38.68 | 3.22 |
| Experiments of 1907: | | | | | | |
| Period I | 2,772.8 | 103.69 | 3.74 | 2,269.9 | 90.34 | 3.98 |
| Period II | 4,301.5 | 150.66 | 3.50 | 3,132.7 | 117.67 | 3.76 |
| Period III | 1,676.4 | 61.45 | 3.67 | 1,562.3 | 59.27 | 3.79 |
| Period IV | 2,693.3 | 97.94 | 3.64 | 2,521.8 | 92.08 | 3.65 |

The average percentage for the experiments of 1905 and 1907 is 3.65. In view of what seem to be the obviously erroneous results in 1906, we have felt justified in using this factor to compute the methane from the digestible carbohydrates. The results of this computation are contained in the following table and are used on succeeding pages in computing the carbon and energy balances:

TABLE 130.—*Computed methane production, 1906.*

| Periods. | Computed carbon in methane. | Equivalent methane. | Equivalent hydrogen. | Equivalent. energy. |
|---|---|---|---|---|
| *Steer A.* | *Grams.* | *Grams.* | *Grams.* | *Calories.* |
| I | 83.68 | 111.80 | 28.12 | 1,491.81 |
| II | 128.63 | 171.85 | 43.22 | 2,293.16 |
| III | 46.63 | 62.30 | 15.67 | 831.30 |
| IV | 74.73 | 99.84 | 25.11 | 1,332.26 |
| *Steer B.* | | | | |
| I | 68.62 | 91.68 | 23.06 | 1,223.33 |
| II | 84.39 | 112.75 | 28.36 | 1,504.47 |
| III | 45.23 | 60.43 | 15.20 | 806.34 |
| IV | 66.55 | 88.91 | 22.36 | 1,186.43 |

## THE BALANCE OF MATTER.

From the data on previous pages, the balances following, including the water balance for the two days in the calorimeter, have been computed in the same manner as for the previous year's experiments.

TABLE 131.—*The balance of matter per day and head, 1906.*

| | Dry matter. | Water. | | Nitrogen. | | Carbon. | | Organic hydrogen. | |
|---|---|---|---|---|---|---|---|---|---|
| | | Income. | Outgo. | Income. | Outgo. | Income. | Outgo. | Income. | Outgo. |
| *Period I.* | | | | | | | | | |
| Steer A: | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Timothy hay | 2,607.9 | 175 | | 34.5 | | 1,213.2 | | 183.1 | |
| Wheat bran | 259.8 | 318 | | 8.1 | | 117.0 | | 18.0 | |
| Corn meal | 734.9 | | | 13.0 | | 337.3 | | 51.7 | |
| Linseed meal | 797.3 | | | 49.5 | | 384.1 | | 54.5 | |
| Water | | 10,180 | | | | | | | |
| Feces | 1,465.1 | | 6,198 | | 31.3 | | 699.9 | | 93.5 |
| Urine | 438.9 | | 3,848 | | 69.0 | | 100.5 | | 17.7 |
| Brushings and hair | 22.4 | | | | 1.6 | | 9.4 | | 1.3 |
| Methane (computed) | 111.8 | | | | | | 83.7 | | 28.1 |
| Carbon dioxid | 3,830.9 | | | | | | 1,044.7 | | |
| Water vapor | | | 3,563 | | | | | | |
| Organic hydrogen oxidized | | 1,342 | | | | | | | 149.9 |
| Gain or loss by body— | | | | | | | | | |
| Protein | 19.2 | | | | 3.2 | | 10.1 | | 1.4 |
| Fat | 135.0 | | | | | | 103.3 | | 16.2 |
| Water | | 1,594 | | | | | | | |
| | | 13,609 | 13,609 | 105.1 | 105.1 | 2,051.6 | 2,051.6 | 307.3 | 307.3 |
| Steer B: | | | | | | | | | |
| Timothy hay | 2,433.1 | 173 | | 32.2 | | 1,131.9 | | 170.8 | |
| Wheat bran | 173.2 | 200 | | 5.4 | | 78.0 | | 12.0 | |
| Corn meal | 490.0 | | | 8.6 | | 224.9 | | 34.5 | |
| Linseed meal | 531.5 | | | 33.0 | | 256.1 | | 36.4 | |
| Water | | 10,003 | | | | | | | |
| Feces | 1,259.7 | | 4,381 | | 25.2 | | 606.7 | | 79.9 |
| Urine | 351.9 | | 2,064 | | 55.0 | | 90.4 | | 13.4 |
| Brushings and hair | 20.0 | | | | 1.3 | | 8.1 | | 1.1 |
| Methane (computed) | 91.7 | | | | | | 68.6 | | 23.1 |
| Carbon dioxid | 3,560.7 | | | | | | 971.0 | | |
| Water vapor | | | 3,841 | | | | | | |
| Organic hydrogen oxidized | | 1,302 | | | | | | | 144.5 |
| Gain or loss by body— | | | | | | | | | |
| Protein | 13.8 | | | 2.3 | | 7.3 | | 1.0 | |
| Fat | 60.9 | | | | | 46.6 | | 7.8 | |
| Water | | | 1,392 | | | | | | |
| | | 11,678 | 11,678 | 81.5 | 81.5 | 1,744.8 | 1,744.8 | 262.0 | 262.0 |
| *Period II.* | | | | | | | | | |
| Steer A: | | | | | | | | | |
| Timothy hay | 2,630.9 | 250 | | 34.9 | | 1,227.3 | | 168.1 | |
| Wheat bran | 596.4 | 710 | | 17.8 | | 271.6 | | 41.2 | |
| Corn meal | 1,733.3 | | | 27.2 | | 801.7 | | 123.6 | |
| Linseed meal | 1,843.0 | | | 108.4 | | 887.6 | | 126.8 | |
| Water | | 15,528 | | | | | | | |
| Feces | 2,174.3 | | 11,194 | | 58.2 | | 1,045.8 | | 145.0 |
| Urine | 588.8 | | 5,661 | | 134.2 | | 160.6 | | 28.5 |
| Brushings and hair | 22.4 | | | | 1.6 | | 9.4 | | 1.3 |
| Methane (computed) | 171.9 | | | | | | 128.6 | | 43.2 |
| Carbon dioxid | 5,511.1 | | | | | | 1,502.9 | | |
| Water vapor | | | 5,853 | | | | | | |
| Organic hydrogen oxidized | | 1,690 | | | | | | | 187.8 |
| Gain or loss by body— | | | | | | | | | |
| Protein | 34.2 | | | 5.7 | | 18.0 | | 2.4 | |
| Fat | 469.2 | | | | | | 358.9 | | 56.3 |
| Water | | 4,530 | | | | | | | |
| | | 22,708 | 22,708 | 194.0 | 194.0 | 3,206.2 | 3,206.2 | 462.1 | 462.1 |
| Steer B: | | | | | | | | | |
| Timothy hay | 2,453.9 | 233 | | 32.5 | | 1,144.7 | | 156.8 | |
| Wheat bran | 304.2 | 376 | | 9.1 | | 138.5 | | 21.0 | |
| Corn meal | 884.8 | | | 13.9 | | 409.2 | | 63.1 | |
| Linseed meal | 940.0 | | | 55.3 | | 452.7 | | 64.7 | |
| Water | | 9,420 | | | | | | | |
| Feces | 1,614.5 | | 7,252 | | 85.0 | | 769.6 | | 105.7 |
| Urine | 402.7 | | 3,193 | | 75.7 | | 112.1 | | 19.1 |

TABLE 131.—*The balance of matter per day and head, 1906*—Continued.

| | Dry matter. | Water. | | Nitrogen. | | Carbon. | | Organic hydrogen. | |
|---|---|---|---|---|---|---|---|---|---|
| | | Income. | Outgo. | Income. | Outgo. | Income. | Outgo. | Income. | Outgo. |
| *Period II*—Continued. | | | | | | | | | |
| Steer B—Continued. | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams:* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Brushings and hair.. | 20.0 | | | | 1.3 | | 8.1 | | 1.1 |
| Methane(computed). | 112.8 | | | | | | 84.4 | | 28.4 |
| Carbon dioxid....... | 3,963.8 | | | | | | 1,080.9 | | |
| Water vapor........ | | | 3,923 | | | | | | |
| Organic hydrogen oxidized.......... | | 1,234 | | | | | | | 137.1 |
| Gain or loss by body— | | | | | | | | | |
| Protein.......... | 7.2 | | | 1.2 | | 3.8 | | 0.5 | |
| Fat............. | 122.6 | | | | | | 93.8 | | 14.7 |
| Water.......... | | 3,105 | | | | | | | |
| | | 14,368 | 14,368 | 112.0 | 112.0 | 2,148.9 | 2,148.9 | 306.1 | 306.1 |
| *Period III.* | | | | | | | | | |
| Steer A: | | | | | | | | | |
| Timothy hay........ | 2,647.2 | 206 | | 33.0 | | 1,252.7 | | 172.6 | |
| Water............. | | 7,115 | | | | | | | |
| Feces............. | 1,199.1 | | 4,644 | | 20.5 | | 589.2 | | 78.5 |
| Urine............. | 324.8 | | 3,214 | | 33.3 | | 67.6 | | 9.7 |
| Brushings and hair.. | 22.4 | | | | 1.6 | | 9.4 | | 1.3 |
| Methane(computed). | 62.3 | | | | | | 46.6 | | 15.7 |
| Carbon dioxid....... | 2,802.7 | | | | | | 764.3 | | |
| Water vapor........ | | | 2,467 | | | | | | |
| Organic hydrogen oxidized.......... | | 910 | | | | | | | 101.1 |
| Gain or loss by body— | | | | | | | | | |
| Protein.......... | 134.4 | | | 22.4 | | 70.6 | | 9.6 | |
| Fat............. | 201.1 | | | | | 153.8 | | 24.1 | |
| Water.......... | | 2,094 | | | | | | | |
| | | 10,325 | 10,325 | 55.4 | 55.4 | 1,477.1 | 1,477.1 | 206.3 | 206.3 |
| Steer B: | | | | | | | | | |
| Timothy hay........ | 2,470.3 | 165 | | 30.8 | | 1,169.0 | | 161.1 | |
| Water............. | | 9,913 | | | | | | | |
| Feces............. | 1,076.9 | | 3,742 | | 18.2 | | 533.0 | | 71.1 |
| Urine............. | 245.9 | | 2,018 | | 27.5 | | 56.8 | | 8.8 |
| Brushings and hair.. | 20.0 | | | | 1.3 | | 8.1 | | 1.1 |
| Methane(computed). | 60.4 | | | | | | 45.2 | | 15.2 |
| Carbon dioxid....... | 2,592.4 | | | | | | 707.0 | | |
| Water vapor........ | | | 2,408 | | | | | | |
| Organic hydrogen oxidized.......... | | 830 | | | | | | | |
| Gain or loss by body— | | | | | | | | | |
| Protein.......... | 97.2 | | | 16.2 | | 51.1 | | 6.9 | |
| Fat............. | 169.9 | | | | | 130.0 | | 20.4 | |
| Water.......... | | | 2,740 | | | | | | 92.2 |
| | | 10.908 | 10,908 | 47.0 | 47.0 | 1,350.1 | 1.350.1 | 188.4 | 188.4 |
| *Period IV.* | | | | | | | | | |
| Steer A: | | | | | | | | | |
| Timothy hay........ | 4,424.5 | 325 | | 59.9 | | 2,067.1 | | 281.0 | |
| Water............. | | 10,078 | | | | | | | |
| Feces............. | 2,075.1 | | 9,615 | | 34.7 | | 1,013.9 | | 131.4 |
| Urine............. | 351.5 | | 3,587 | | 30.8 | | 85.1 | | 12.0 |
| Brushings and hair.. | 22.4 | | | | 1.6 | | 9.4 | | 1.3 |
| Methane(computed). | 99.8 | | | | | | 74.7 | | 25.1 |
| Carbon dioxid....... | 3,352.7 | | | | | | 914.3 | | |
| Water vapor........ | | | 3,140 | | | | | | |
| Organic hydrogen oxidized.......... | | 1,040 | | | | | | | 115.5 |
| Gain or loss by body— | | | | | | | | | |
| Protein.......... | 43.2 | | | 7.2 | | 22.7 | | 3.1 | |
| Fat............. | 9.9 | | | | | 7.6 | | 1.2 | |
| Water.......... | | 4,899 | | | | | | | |
| | | 16,342 | 16,342 | 67.1 | 67.1 | 2,097.4 | 2,097.4 | 285.3 | 285.3 |

TABLE 131.—*The balance of matter per day and head, 1906*—Continued.

| | Dry matter. | Water. | | Nitrogen. | | Carbon. | | Organic hydrogen. | |
|---|---|---|---|---|---|---|---|---|---|
| | | Income. | Outgo. | Income. | Outgo. | Income. | Outgo. | Income. | Outgo. |
| *Period IV*—Continued. | | | | | | | | | |
| Steer B: | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Timothy hay | 3,805.1 | 275 | | 51.5 | | 1,777.7 | | 241.6 | |
| Water | | 11,090 | | | | | | | |
| Feces | 1,717.9 | | 6,961 | | 29.5 | | 851.2 | | 115.6 |
| Urine | 338.5 | | 2,547 | | 30.2 | | 78.5 | | 14.0 |
| Brushings and hair | 20.0 | | | | 1.3 | | 8.1 | | 1.1 |
| Methane (computed) | 88.9 | | | | | | 66.6 | | 22.4 |
| Carbon dioxid | 2,999.6 | | | | | | 818.0 | | |
| Water vapor | | | 2,655 | | | | | | |
| Organic hydrogen oxidized | | 854 | | | | | | | 94.9 |
| Gain or loss by body— | | | | | | | | | |
| Protein | 57.0 | | | 9.5 | | 29.9 | | 4.1 | |
| Fat | 19.3 | | | | | 14.8 | | 2.3 | |
| Water | | | 56 | | | | | | |
| | | 12,219 | 12,219 | 61.0 | 61.0 | 1,822.4 | 1,822.4 | 248.0 | 248.0 |

## COMPUTED GAINS OR LOSSES OF LIVE WEIGHT IN THE CALORIMETER.

Table 132 summarizes the single factors which make up the estimated gain or loss of live weight by the animal while in the calorimeter as computed from the data of Table 131 in the same manner as in the experiments of 1905 (p. 109.)

TABLE 132.—*Computed daily gains or losses of live weight in the calorimeter, 1906.*

| | Period I. | | Period II. | | Period III. | | Period IV. | |
|---|---|---|---|---|---|---|---|---|
| | Loss. | Gain. | Loss. | Gain. | Loss. | Gain. | Loss. | Gain. |
| *Steer A.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Protein | | 19 | 34 | | 134 | | 43 | |
| Fat | | 135 | | 469 | 201 | | 10 | |
| Water | 1,594 | | 4,530 | | 2,094 | | 4,999 | |
| Correction for irregularity of excretion | | | 29 | | 3 | | 46 | |
| Balance | | 1,440 | | 4,124 | | 2,432 | | 5,098 |
| Total | 1,594 | 1,594 | 4,593 | 4,593 | 2,432 | 2,432 | 5,098 | 5,098 |
| *Steer B.* | | | | | | | | |
| Protein | 14 | | 7 | | 97 | | 57 | |
| Fat | 61 | | | 123 | 170 | | 19 | |
| Water | | 1,392 | 3,105 | | | 2,740 | | 56 |
| Correction for irregularity of excretion | | 26 | 30 | | | 10 | 1 | |
| Balance | 1,343 | | | 3,019 | 2,483 | | | 21 |
| Total | 1,418 | 1,418 | 3,142 | 3,142 | 2,750 | 2,750 | 77 | 77 |

## COMPARISON OF OBSERVED AND COMPUTED GAIN OR LOSS OF LIVE WEIGHT.

The respiration calorimeter is not provided with means for taking the weight of the animal while in the respiration chamber. Its weight was taken, however, immediately before entering and immediately after leaving the apparatus, the time of weighing being noted, while the weights of the visible excreta for the four or five hours preliminary to the actual experiment were recorded in the last three periods.

While it is not possible to compute a complete balance for these preliminary hours, if we may assume that the excretion of carbon dioxid and water went on at the same rate as in the experiment proper, we have sufficient data for an approximate computation of the loss in weight during the preliminary hours. This can then be combined with the computed loss of weight in the 48 hours of the experiment proper and the result compared with that of the actual weighing. It scarcely need be said that such a comparison can be nothing more than a general check upon the accuracy of the work. An exact agreement could not be looked for, but any gross error in the experiments would probably be revealed. The method for computing the correction may be conveniently illustrated by the results for steer A in Period II. The animal entered the calorimeter at 1.38 p. m., the preliminary period thus amounting to 262 minutes. During this time neither food nor drink was consumed and a loss of weight must have taken place, due to the continued excretion. The amounts of the visible excreta which were recorded need simply to be deducted from the live weight. This is not true of the carbon dioxid and water excreted, since at least a considerable part of their oxygen is derived from the air and we have no experimental data as to the amount of the latter taken up. For the purpose of this approximate computation, however, it seems permissible to neglect the katabolism of the protein and to consider only the nonnitrogenous material oxidized. If this consisted only of carbohydrates—that is, if the respiratory quotient was equal to one—the corresponding loss of weight by the animal would evidently be equal to the water given off plus the carbon of the carbon dioxid excreted. If some of the material oxidized consisted of fat, however, the loss of weight would be less than that indicated above, since some of the oxygen of the water eliminated as well as all that contained in the carbon dioxid would have been derived from the air. On the other hand, if a formation of fat from carbohydrates took place, the contrary would be true, some of the oxygen of the carbon dioxid being derived from the carbohydrates consumed and not from the air. On the basis of the average composition of animal fat, viz,

C=76.5
H=12.0
O=11.5

the following correction may be computed:

*Oxidation of 100 grams of fat.*

| | Grams. |
|---|---|
| O required for oxidation of H | 96.0 |
| O contained in fat | 11.5 |
| O derived from atmosphere | 84.5 |

*Formation of 100 grams of fat.*

| | Grams. |
|---|---|
| $C_6H_{12}O_6$ required to furnish C | 191.25 |
| O in 191.25 grams $C_6H_{12}O_6$ | 102.0 |
| O in 100 grams fat | 11.5 |
| O of carbohydrate excreted in $CO_2$ | 90.5 |

On the above basis, we may compute the change in weight by steer A in Period II as follows:

| | Grams. |
|---|---|
| *In preliminary period* (262 minutes): | |
| Feces | 130 |
| Urine | 1,470 |
| Methane $93.3\times\frac{262}{1440}$ | 17 |
| C of $CO_2$ $1,502.9\times\frac{262}{1440}$ | 273 |
| Water vapor $5,853\times\frac{262}{1440}$ | 1,065 |
| Oxygen equivalent to fat gained $4.692\times90.5\times\frac{262}{1440}$ | 77 |
| *In calorimeter period:* | |
| Net loss, Table 132, computed to 48 hours | 8,248 |
| Computed loss of weight | 11,270 |
| Actual loss of weight | 11,800 |

A similar computation for the several periods, with the exception of the first, for which the weights of feces and urine excreted during the preliminary period were not recorded, gives the following comparison:

TABLE 133.—*Computed and observed gains in live weight, 1906.*

| | Computed. | Observed. |
|---|---|---|
| *Period II.* | *Kilos.* | *Kilos.* |
| Steer A | −11.3 | −11.8 |
| Steer B | − 7.5 | − 8.2 |
| *Period III.* | | |
| Steer A | − 5.6 | − 5.3 |
| Steer B | + 4.5 | + 4.2 |
| *Period IV.* | | |
| Steer A | −11.8 | −11.9 |
| Steer B | − 2.6 | − 2.9 |

The generally good agreement in the foregoing table indicates at least that no gross errors have crept into the work, while it also tends to confirm our confidence in the reasonable accuracy of the computations of the nature of the gain or loss which are contained in Table 132.

## HEAT EMISSION AND HEAT PRODUCTION.

The following tables show the results of the determinations of the heat given off by the animals, and likewise the heat production computed by correcting for the gain or loss of matter by the body in the manner described in connection with the experiments of 1905 (pp. 112–113).

TABLE 134.—*Heat emission, 1906.*

| | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | By radiation. | As latent heat of water vapor. | Total. | By radiation. | As latent heat of water vapor. | Total. |
| *Period I.* | | | | | | |
| First day: | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Subperiod 1 | 3,752.2 | 1,124.6 | 4,876.8 | 3,516.0 | 1,175.8 | 4,691.8 |
| Subperiod 2 | 3,715.5 | 1,031.2 | 4,746.7 | 3,125.0 | 1,147.7 | 4,272.7 |
| Total | 7,467.7 | 2,155.8 | 9,623.5 | 6,641.0 | 2,323.5 | 8,964.5 |
| Second day: | | | | | | |
| Subperiod 3 | 3,497.8 | 1,061.0 | 4,548.8 | 3,305.3 | 1,085.4 | 4,390.7 |
| Subperiod 4 | 3,593.0 | 975.1 | 4,568.1 | 3,359.6 | 1,101.3 | 4,460.9 |
| Total | 7,090.8 | 2,026.1 | 9,116.9 | 6,664.9 | 2,186.7 | 8,851.6 |
| Daily average | 7,279.2 | 2,091.0 | 9,370.2 | 6,653.0 | 2,255.1 | 8,908.1 |
| *Period II.* | | | | | | |
| First day: | | | | | | |
| Subperiod 1 | [1] 4,810.2 | 1,756.2 | 6,566.4 | [2] 3,779.3 | 1,187.6 | 4,966.9 |
| Subperiod 2 | 4,760.3 | 1,627.5 | 6,387.8 | 3,685.0 | 1,140.6 | 4,825.6 |
| Total | 9,570.5 | 3,383.7 | 12,954.2 | 7,464.3 | 2,328.2 | 9,792.5 |
| Second day: | | | | | | |
| Subperiod 3 | 4,843.8 | 1,807.5 | 6,651.3 | 3,776.0 | 1,104.8 | 4,880.8 |
| Subperiod 4 | 4,629.0 | 1,680.2 | 6,309.2 | 3,749.8 | 1,172.8 | 4,922.6 |
| Total | 9,472.8 | 3,487.7 | 12,960.5 | 7,525.8 | 2,277.6 | 9,803.4 |
| Daily average | 9,521.7 | 3,435.7 | 12,957.4 | 7,495.1 | 2,302.9 | 9,798.0 |
| *Period III.* | | | | | | |
| First day: | | | | | | |
| Subperiod 1 | 2,944.7 | 757.2 | 3,701.9 | 2,705.2 | 756.8 | 3,462.0 |
| Subperiod 2 | 3,090.8 | 696.9 | 3,787.7 | 2,698.4 | 686.0 | 3,384.4 |
| Total | 6,035.5 | 1,454.1 | 7,489.6 | 5,403.6 | 1,442.8 | 6,846.4 |
| Second day: | | | | | | |
| Subperiod 3 | 3,060.8 | 729.6 | 3,790.4 | 2,798.1 | 2,716.5 | 3,514.6 |
| Subperiod 4 | 3,005.1 | 712.2 | 3,717.3 | 2,720.5 | 667.0 | 3,387.5 |
| Total | 6,065.9 | 1,441.8 | 7,507.7 | 5,518.6 | 1,383.5 | 6,902.1 |
| Daily average | 6,050.7 | 1,448.0 | 7,498.7 | 5,461.2 | 1,413.1 | 6,874.3 |
| *Period IV.* | | | | | | |
| First day: | | | | | | |
| Subperiod 1 | 3,159.7 | 881.0 | 4,040.7 | 2,968.0 | 809.2 | 3,777.2 |
| Subperiod 2 | 3,182.8 | 872.0 | 4,054.8 | 2,809.4 | 691.2 | 3,500.6 |
| Total | 6,342.5 | 1,753.0 | 8,095.5 | 5,777.4 | 1,500.4 | 7,277.8 |
| Second day: | | | | | | |
| Subperiod 3 | 3,391.0 | 1,021.3 | 4,412.3 | 3,035.4 | 795.0 | 3,830.4 |
| Subperiod 4 | 3,197.4 | 912.1 | 4,109.5 | 2,828.9 | 820.9 | 3,649.8 |
| Total | 6,588.4 | 1,933.4 | 8,521.8 | 5,864.3 | 1,615.9 | 7,480.2 |
| Daily average | 6,465.5 | 1,843.2 | 8,308.7 | 5,820.8 | 1,558.2 | 7,379.0 |

[1] Computed for first 102 minutes from average heat emission standing and lying, page 156.
[2] First 30 minutes computed.

TABLE 135.—*Average heat production, 1906.*

| Period. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Heat emission. | Correction for gain by body. | Heat production. | Heat emission. | Correction for gain by body. | Heat production. |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| I | 9,370.2 | − 31.1 | 9,339.1 | 8,908.1 | +28.8 | 8,936.9 |
| II | 12,957.4 | − 85.7 | 12,871.7 | 9,798.0 | −61.9 | 9,736.1 |
| III | 7,498.7 | − 46.3 | 7,452.4 | 6,874.3 | +54.1 | 6,928.4 |
| IV | 8,308.7 | −100.2 | 8,208.5 | 7,379.0 | + 1.0 | 7,380.0 |

## THE BALANCE OF ENERGY.

The balance of energy in the several periods, computed on the same basis as in the experiments of 1905 (pp. 113–114), is as follows:

TABLE 136.—*The balance of energy per day and head, 1906.*

| Periods and components. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Dry matter. | Energy. | | Dry matter. | Energy. | |
| | | Income. | Outgo. | | Income. | Outgo. |
| *Period I.* | *Grams.* | *Calories.* | *Calories.* | *Grams.* | *Calories.* | *Calories.* |
| Timothy hay | 2,607.9 | 11,691.5 | | 2,433.1 | 10,907.8 | |
| Wheat bran | 259.8 | 1,180.4 | | 173.2 | 786.9 | |
| Corn meal | 734.9 | 3,323.9 | | 490.0 | 2,216.2 | |
| Linseed meal | 797.3 | 3,913.8 | | 531.5 | 2,609.0 | |
| Feces | 1,465.1 | | 6,855.6 | 1,259.7 | | 5,930.0 |
| Urine (corrected for nitrogen) | 438.9 | | 1,041.5 | 351.9 | | 864.3 |
| Methane | 111.8 | | 1,491.8 | 91.7 | | 1,223.3 |
| Metabolizable | | | 10,720.7 | | | 8,502.3 |
| Total | | 20,109.6 | 20,109.6 | | 16,519.9 | 16,519.9 |
| Metabolizable | | 10,720.7 | | | 8,502.3 | |
| Heat | | | 9,339.1 | | | 8,936.9 |
| Brushings | 22.4 | | 103.8 | 20.0 | | 89.4 |
| Gain or loss by body: | | | | | | |
| Protein (corrected for nitrogen) | 19.2 | | 85.6 | 13.8 | 61.6 | |
| Fat | 135.0 | | 1,282.5 | 60.9 | 578.6 | |
| Error | | 90.3 | | | | 116.2 |
| Total | | 10,811.0 | 10,811.0 | | 9,142.5 | 9,142.5 |
| *Period II.* | | | | | | |
| Timothy hay | 2,630.9 | 11,796.2 | | 2,453.9 | 11,002.6 | |
| Wheat bran | 596.4 | 2,691.9 | | 304.2 | 1,373.0 | |
| Corn meal | 1,733.3 | 7,844.7 | | 884.8 | 4,004.6 | |
| Linseed meal | 1,843.0 | 9,052.3 | | 940.0 | 4,617.0 | |
| Feces | 2,174.3 | | 10,196.6 | 1,614.5 | | 7,476.3 |
| Urine (corrected for nitrogen) | 588.8 | | 1,605.0 | 402.7 | | 1,094.3 |
| Methane | 171.9 | | 2,293.2 | 112.8 | | 1,504.5 |
| Metabolizable | | | 17,290.3 | | | 10,922.1 |
| Total | | 31,385.1 | 31,385.1 | | 20,997.2 | 20,997.2 |
| Metabolizable | | 17,290.3 | | | 10,922.1 | |
| Heat | | | 12,871.7 | | | 9,736.1 |
| Brushings | 22.4 | | 103.8 | 20.0 | | 89.4 |
| Gain or loss by body: | | | | | | |
| Protein (corrected for nitrogen) | 34.2 | 152.4 | | 7.2 | 32.1 | |
| Fat | 469.2 | | 4,457.4 | 122.6 | | 1,164.7 |
| Error | | | 9.8 | | 36.0 | |
| Total | | 17,442.7 | 17,442.7 | | 10,990.2 | 10,990.2 |

TABLE 136.—*The balance of energy per day and head, 1906*—Continued.

| Periods and components. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Dry matter. | Energy. | | Dry matter. | Energy. | |
| | | Income. | Outgo. | | Income. | Outgo. |
| *Period III.* | *Grams.* | *Calories.* | *Calories.* | *Grams.* | *Calories.* | *Calories.* |
| Timothy hay | 2,647.2 | 11,938.3 | | 2,470.3 | 11,140.6 | |
| Feces | 1,199.1 | | 5,757.0 | 1,076.9 | | 5,168.3 |
| Urine (corrected for nitrogen) | 324.8 | | 411.2 | 245.9 | | 414.8 |
| Methane | 62.3 | | 831.3 | 60.4 | | 806.3 |
| Metabolizable | | | 4,938.8 | | | 4,751.2 |
| Total | | 11,938.3 | 11,938.3 | | 11,140.6 | 11,140.6 |
| Metabolizable | | 4,938.8 | | | 4,751.2 | |
| Heat | | | 7,452.4 | | | 6,928.4 |
| Brushings | 22.4 | | 103.8 | 20.0 | | 89.4 |
| Gain or loss by body: | | | | | | |
| Protein (corrected for nitrogen) | 134.4 | 599.2 | | 97.2 | 433.3 | |
| Fat | 20.1 | 1,910.5 | | 169.9 | 1,614.1 | |
| Error | | 107.7 | | | 219.2 | |
| Total | | 7,556.2 | 7,556.2 | | 7,017.8 | 7,017.8 |
| *Period IV.* | | | | | | |
| Timothy hay | 4,424.5 | 19,950.2 | | 3,806.1 | 17,157.3 | |
| Feces | 2,075.1 | | 9,957.4 | 1,717.9 | | 8,235.7 |
| Urine (corrected for nitrogen) | 351.5 | | 679.1 | 337.3 | | 635.2 |
| Methane | 99.8 | | 1,332.3 | 88.9 | | 1,186.4 |
| Metabolizable | | | 7,981.4 | | | 7,100.0 |
| Total | | 19,950.2 | 19,950.2 | | 17,157.3 | 17,157.3 |
| Metabolizable | | 7,981.4 | | | 7,100.0 | |
| Heat | | | 8,208.5 | | | 7,380.0 |
| Brushings | 22.4 | | 103.8 | 20.0 | | 89.4 |
| Gain or loss by body: | | | | | | |
| Protein (corrected for nitrogen) | 43.2 | 192.7 | | 57.0 | 254.1 | |
| Fat | 9.2 | 94.1 | | 19.3 | 183.4 | |
| Error | | 44.1 | | | | 68.1 |
| Total | | 8,312.3 | 8,312.3 | | 7,537.5 | 7,537.5 |

It is apparent from the foregoing tabulation that a much better agreement between the observed and computed heat production was obtained in this series of experiments than in those of the previous year, as is clearly shown by the following summary, and also that the differences are in both directions:

TABLE 137.—*Observed and computed daily heat production, 1906.*

| Periods. | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Observed. | Computed. | Error. | Computed + observed. | Observed. | Computed. | Error. | Computed + observed. |
| | *Calories.* | *Calories.* | *Calories.* | *Per cent.* | *Calories.* | *Calories.* | *Calories.* | *Per cent.* |
| I | 9,339.1 | 9,248.8 | − 90.3 | 99.0 | 8,936.9 | 9,053.1 | +116.2 | 101.3 |
| II | 12,871.7 | 12,881.5 | + 9.8 | 100.1 | 9,736.1 | 9,700.1 | − 36.0 | 99.6 |
| III | 7,452.4 | 7,344.7 | −107.7 | 98.6 | 6,928.4 | 6,709.2 | −219.2 | 96.8 |
| IV | 8,208.5 | 8,164.4 | − 44.1 | 99.5 | 7,380.0 | 7,448.1 | + 68.1 | 100.9 |

## METABOLIZABLE ENERGY.

The results for the metabolizable energy of the timothy hay and of the mixed grain in these experiments are tabulated in the following pages in the same form as in the experiments of the previous year (pp. 115–117).

TABLE 138.—*Percentage distribution of energy of timothy hay, 1906.*

| | Total energy. | | | Energy of digested matter. | | |
|---|---|---|---|---|---|---|
| | Period III. | Period IV. | True average. | Period III. | Period IV. | True average. |
| *Steer A.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| In feces | 48.22 | 49.91 | 49.28 | ........ | ........ | ........ |
| In urine | 3.44 | 3.40 | 3.42 | 6.64 | 6.79 | 6.74 |
| In methane | 6.97 | 6.68 | 6.78 | 13.46 | 13.34 | 13.38 |
| Metabolizable | 41.37 | 40.01 | 40.52 | 79.90 | 79.87 | 79.88 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| *Steer B.* | | | | | | |
| In feces | 46.39 | 48.00 | 47.37 | ........ | ........ | ........ |
| In urine | 3.72 | 3.70 | 3.71 | 6.94 | 7.12 | 7.05 |
| In methane | 7.24 | 6.92 | 7.04 | 13.51 | 13.30 | 13.38 |
| Metabolizable | 42.65 | 41.38 | 41.88 | 79.55 | 79.58 | 79.57 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

TABLE 139.—*Metabolizable energy per gram of organic matter of timothy hay, 1906.*

| Periods. | Organic matter. | | Metabolizable energy. | | |
|---|---|---|---|---|---|
| | Total. | Digested. | Total. | Per gram total organic matter. | Per gram digested organic matter. |
| *Steer A.* | *Grams.* | *Grams.* | *Calories.* | *Calories.* | *Calories.* |
| III | 2,493.1 | 1,373.1 | 4,938.8 | 1.981 | 3.597 |
| IV | 4,164.8 | 2,238.1 | 7,981.4 | 1.916 | 3.566 |
| Totals and averages | 6,657.9 | 3,611.2 | 12,920.2 | 1.941 | 3.578 |
| *Steer B.* | | | | | |
| III | 2,326.5 | 1,332.6 | 4,751.2 | 2.042 | 3.565 |
| IV | 3,581.7 | 1,991.8 | 7,100.0 | 1.982 | 3.565 |
| Totals and averages | 5,908.2 | 3,324.4 | 11,851.2 | 2.006 | 3.565 |

TABLE 140.—*Percentage distribution of energy of mixed grain, 1906.*

| | Organic matter. | | Total energy. | Energy of excreta. | | | Metabolizable energy. |
|---|---|---|---|---|---|---|---|
| | Total. | Digested. | | Feces. | Urine (corrected). | Methane (computed). | |
| ***Steer A.*** | | | | | | | |
| Period I: | *Grams.* | *Grams.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| In total ration | 4,176.3 | 2,849.9 | 20,109.6 | 6,855.6 | 1,041.5 | 1,491.8 | 10,720.7 |
| In hay | 2,459.0 | 1,333.8 | 11,691.5 | 5,761.6 | 399.8 | 792.7 | 4,737.4 |
| In grain | 1,717.3 | 1,516.1 | 8,418.1 | 1,094.0 | 641.7 | 699.1 | 5,983.3 |
| Per cent of total energy | | | 100.00 | 13.00 | 7.62 | 8.30 | 71.08 |
| Per cent of digested energy | | | | | 8.76 | 9.54 | 81.70 |
| Period II: | | | | | | | |
| In total ration | 6,486.4 | 4,496.9 | 31,385.1 | 10,196.6 | 1,605.0 | 2,293.2 | 17,290.3 |
| In hay | 2,487.5 | 1,349.2 | 11,796.2 | 5,813.2 | 403.4 | 799.8 | 4,779.8 |
| In grain | 3,998.9 | 3,147.7 | 19,588.9 | 4,383.4 | 1,201.6 | 1,493.4 | 12,510.5 |
| Per cent of total energy | | | 100.00 | 22.38 | 6.13 | 7.63 | 63.86 |
| Per cent of digested energy | | | | | 7.90 | 9.83 | 82.27 |
| ***Steer B.*** | | | | | | | |
| Period I: | | | | | | | |
| In total ration | 3,439.0 | 2,293.7 | 16,519.9 | 5,930.0 | 864.3 | 1,223.3 | 8,502.3 |
| In hay | 2,294.2 | 1,290.9 | 10,907.8 | 5,167.0 | 404.7 | 767.9 | 4,568.2 |
| In grain | 1,144.8 | 1,002.8 | 5,612.1 | 763.0 | 459.6 | 455.4 | 3,934.1 |
| Per cent of total energy | | | 100.00 | 13.60 | 8.19 | 8.11 | 70.10 |
| Per cent of digested energy | | | | | 9.48 | 9.38 | 81.14 |
| Period II: | | | | | | | |
| In total ration | 4,360.4 | 2,884.9 | 20,997.2 | 7,476.3 | 1,094.3 | 1,504.5 | 10,922.1 |
| In hay | 2,320.2 | 1,305.6 | 11,002.6 | 5,211.9 | 408.2 | 774.6 | 4,607.9 |
| In grain | 2,040.2 | 1,579.3 | 9,994.6 | 2,264.4 | 686.1 | 729.9 | 6,314.2 |
| Per cent of total energy | | | 100.00 | 22.66 | 6.86 | 7.30 | 63.18 |
| Per cent of digested energy | | | | | 8.89 | 9.44 | 81.67 |

TABLE 141.—*Metabolizable energy per gram organic matter of mixed grain, 1906.*

| Periods. | Organic matter. | | Metabolizable energy. | | |
|---|---|---|---|---|---|
| | Total. | Digested. | Total. | Per gram total organic matter. | Per gram digested organic matter. |
| ***Steer A.*** | *Grams.* | *Grams.* | *Calories.* | *Calories.* | *Calories.* |
| I | 1,717.3 | 1,516.1 | 5,983.3 | 3.484 | 3.946 |
| II | 3,998.9 | 3,147.7 | 12,510.5 | 3.128 | 3.974 |
| | 5,716.2 | | | 3.306 | |
| ***Steer B.*** | | | | | |
| I | 1,144.8 | 1,002.8 | 3,934.4 | 3,437 | 3.923 |
| II | 2,040.2 | 1,579.3 | 6,314.2 | 3.095 | 3.998 |
| | 3,185.0 | | | 3.266 | |

## CORRECTION OF HEAT PRODUCTION FOR STANDING AND LYING.

### HEAT EMITTED BY RADIATION AND CONDUCTION.

The foregoing results for heat production have still to be corrected for differences in the amount of time spent standing and lying, in accordance with the methods discussed on pages 41 and 118. The following tables show for each period the results in the individual sections which were selected for comparison and likewise the average heat emitted per minute by radiation and conduction during the several periods and brought out of the apparatus in the water current.

TABLE 142.—*Heat emitted by radiation and conduction during periods of standing and lying, 1906.*

| Periods. | Standing. | | Lying. | |
|---|---|---|---|---|
| | Elapsed time. | Total heat. | Elapsed time. | Total heat. |
| *Period I.* | | | | |
| Steer A: | *Minutes.* | *Calories.* | *Minutes.* | *Calories.* |
| 6.00 p. m. to 8.08 p. m. | 128 | 702.99 | | |
| 9.16 p. m. to 9.44 p. m. | | | 28 | 114.73 |
| 10.12 p. m. to 11.36 p. m. | 84 | 512.99 | | |
| 11.56 p. m. to 1.36 a. m. | | | 100 | 444.92 |
| 2.40 a. m. to 3.32 a. m. | | | 52 | 232.62 |
| 4.28 a. m. to 5.56 a. m. | 92 | 539.02 | | |
| 6.00 a. m. to 9.04 a. m. | 184 | 971.02 | | |
| 9.24 a. m. to 12.16 p. m. | | | 172 | 691.96 |
| 12.36 p. m. to 5.36 p. m. | 324 | 1,830.76 | | |
| 6.00 p. m. to 7.20 p. m. | 80 | 442.59 | | |
| 7.48 p. m. to 10.08 p. m. | | | 140 | 395.68 |
| 11.36 p. m. to 2.32 a. m. | | | 176 | 809.21 |
| 3.44 a. m. to 5.00 a. m. | | | 76 | 339.67 |
| 5.20 a. m. to 5.56 a. m. | 40 | 249.08 | | |
| 6.00 a. m. to 7.16 a. m. | 76 | 440.23 | | |
| 7.48 a. m. to 9.56 a. m. | | | 128 | 510.62 |
| 10.20 a. m. to 11.20 a. m. | 60 | 337.82 | | |
| 12.00 p. m. to 3.04 p. m. | | | 184 | 867.74 |
| 3.32 p. m. to 6.00 p. m. | 148 | 865.33 | | |
| Totals | 1,216 | 6,890.91 | 1,056 | 4,607.18 |
| Total corrections for capacity, feed, water, excreta, etc | | +79.51 | | −96.40 |
| | | 6,970.42 | | 4,510.78 |
| Heat per minute | | 5.7323 | | 4.2716 |
| Steer B: | | | | |
| 6.40 p. m. to 9.20 p. m. | 160 | 907.02 | | |
| 10.20 p. m. to 11.48 p. m. | | | 88 | 348.56 |
| 12.08 a. m. to 12.36 a. m. | 28 | 160.41 | | |
| 12.36 a. m. to 2.32 a. m. | 116 | 680.21 | | |
| 3.20 a. m. to 4.40 a. m. | | | 80 | 300.47 |
| 5.04 a. m. to 6.00 a. m. | 56 | 312.26 | | |
| 6.00 a. m. to 7.20 a. m. | 80 | 401.12 | | |
| 8.00 a. m. to 10.16 a. m. | 136 | 681.08 | | |
| 10.40 a. m. to 4.32 p. m. | | | 352 | 1,291.61 |
| 4.52 p. m. to 6.00 p. m. | 68 | 373.93 | | |
| 6.00 p. m. to 7.16 p. m. | 76 | 416.38 | | |
| 7.44 p. m. to 10.40 p. m. | | | 176 | 710.12 |
| 10.40 p. m. to 4.12 a. m. | | | 332 | 1,434.06 |
| 5.08 a. m. to 6.00 a. m. | 52 | 292.40 | | |
| 6.00 a. m. to 9.36 a. m. | 216 | 1,128.18 | | |
| 9.56 a. m. to 11.04 a. m. | | | 68 | 234.06 |
| 11.04 a. m. to 2.48 p. m. | 204 | 1,086.13 | | |
| 3.20 p. m. to 6.00 p. m. | | | 160 | 574.53 |
| Totals | 1,192 | 6,439.12 | 1,256 | 4,893.41 |
| Total corrections for capacity, feed, water, excreta, etc | | −23.24 | | −13.85 |
| | | 6,415.88 | | 4,879.56 |
| Heat per minute | | 5.3824 | | 3.8850 |

TABLE 142.—*Heat emitted by radiation and conduction during periods of standing and lying, 1906*—Continued.

| Periods. | Standing. | | Lying. | |
|---|---|---|---|---|
| | Elapsed time. | Total heat. | Elapsed time. | Total heat. |
| *Period II.* | | | | |
| Steer A: | *Minutes.* | *Calories.* | *Minutes.* | *Calories.* |
| 8.52 p. m. to 9.28 p. m. | | | 36 | 220.89 |
| 9.48 p. m. to 10.44 p. m. | 56 | 444.81 | | |
| 11.16 p. m. to 11.28 p. m. | 12 | 96.06 | | |
| 11.28 p. m. to 12.40 a. m. | 72 | 562.22 | | |
| 1.00 a. m. to 2.24 a. m. | 84 | 608.58 | | |
| 2.44 a. m. to 4.56 a. m. | | | 132 | 667.92 |
| 5.20 a. m. to 6.00 a. m. | 40 | 286.74 | | |
| 6.00 a. m. to 8.16 a. m. | 136 | 929.83 | | |
| 8.40 a. m. to 9.14 a. m. | | | 34 | 175.09 |
| 9.14 a. m. to 9.44 a. m. | | | 30 | 162.88 |
| 10.00 a. m. to 10.23 a. m. | 23 | 168.54 | | |
| 10.23 a. m. to 11.08 a. m. | 45 | 338.53 | | |
| 11.52 a. m. to 12.24 p. m. | | | 32 | 186.74 |
| 12.40 p. m. to 12.575 p. m. | 17.5 | 130.45 | | |
| 12.575 p. m. to 1.185 p. m. | 21 | 161.15 | | |
| 1.185 p. m. to 1.36 p. m. | 17.5 | 140.66 | | |
| 2.08 p. m. to 2.48 p. m. | 40 | 294.51 | | |
| 3.12 p. m. to 4.48 p. m. | | | 96 | 494.25 |
| 5.08 p. m. to 6.00 p. m. | 52 | 389.24 | | |
| 6.00 p. m. to 7.44 p. m. | 104 | 767.30 | | |
| 8.08 p. m. to 9.20 p. m. | | | 72 | 398.48 |
| 9.40 p. m. to 12.24 a. m. | 164 | 1,283.57 | | |
| 12.44 a. m. to 1.16 a. m. | | | 32 | 178.43 |
| 1.36 a. m. to 1.56 a. m. | 20 | 157.13 | | |
| 2.16 a. m. to 4.20 a. m. | | | 124 | 676.29 |
| 4.40 a. m. to 6.00 a. m. | 80 | 591.34 | | |
| 6.00 a. m. to 7.56 a. m. | 116 | 780.21 | | |
| 8.32 a. m. to 10.08 a. m. | | | 96 | 504.22 |
| 10.28 a. m. to 10.48 a. m. | 20 | 151.85 | | |
| 11.08 a. m. to 12.56 p. m. | | | 108 | 588.97 |
| 1.16 p. m. to 1.56 p. m. | 40 | 338.55 | | |
| 2.16 p. m. to 3.52 p. m. | | | 96 | 504.29 |
| 4.12 p. m. to 6.00 p. m. | 108 | 837.81 | | |
| Totals | 1,268 | 9,459.08 | 888 | 4,758.45 |
| Total corrections for capacity, feed, water, excreta, etc | | +110.37 | | −118.70 |
| | | 9,569.45 | | 4,639.75 |
| Heat per minute | | 7.5469 | | 5.2249 |
| Steer B: | | | | |
| 6.52 p. m. to 8.04 p. m. | 72 | 412.48 | | |
| 8.28 p. m. to 9.56 p. m. | | | 88 | 358.68 |
| 10.16 p. m. to 11.36 p. m. | 80 | 520.34 | | |
| 12.00 a. m. to 1.36 a. m. | | | 96 | 427.46 |
| 2.00 a. m. to 4.40 a. m. | | | 160 | 730.79 |
| 5.00 a. m. to 6.00 a. m. | 60 | 369.97 | | |
| 6.00 a. m. to 7.44 a. m. | 104 | 617.37 | | |
| 8.08 a. m. to 10.52 a. m. | | | 164 | 700.95 |
| 11.12 a. m. to 1.36 p. m. | 144 | 897.29 | | |
| 2.00 p. m. to 4.48 p. m. | | | 168 | 705.54 |
| 5.04 p. m. to 6.00 p. m. | 56 | 332.86 | | |
| 6.00 p. m. to 8.00 p. m. | 120 | 703.06 | | |
| 8.20 p. m. to 9.32 p. m. | | | 72 | 305.02 |
| 9.52 p. m. to 11.12 p. m. | 80 | 524.44 | | |
| 11.36 p. m. to 12.52 a. m. | | | 76 | 333.91 |
| 1.12 a. m. to 2.00 a. m. | 48 | 321.66 | | |
| 2.24 a. m. to 5.28 a. m. | | | 184 | 821.57 |
| 6.00 a. m. to 7.28 a. m. | 88 | 532.36 | | |
| 8.00 a. m. to 10.56 a. m. | | | 176 | 737.02 |
| 11.16 a. m. to 12.32 p. m. | 76 | 490.99 | | |
| 12.56 p. m. to 3.24 p. m. | | | 148 | 612.76 |
| 3.44 p. m. to 6.00 p. m. | 136 | 785.91 | | |
| Totals | 1,064 | 6,508.93 | 1,332 | 5,733.70 |
| Total corrections for capacity, water, feed, excreta, etc | | +54.17 | | −44.81 |
| | | 6,563.10 | | 5,688.89 |
| Heat per minute | | 6.1683 | | 4.2709 |

TABLE 142.—*Heat emitted by radiation and conduction during periods of standing and lying, 1906*—Continued.

| Periods. | Standing. | | Lying. | |
|---|---|---|---|---|
| | Elapsed time. | Total heat. | Elapsed time. | Total heat. |
| *Period III.* | | | | |
| Steer A: | *Minutes.* | *Calories.* | *Minutes.* | *Calories.* |
| 6.00 p. m. to 9.08 p. m. | 188 | 768.07 | | |
| 10.20 p. m. to 1.16 a. m. | | | 176 | 648.79 |
| 1.36 a. m. to 3.08 a. m. | 92 | 486.12 | | |
| 3.32 a. m. to 5.08 a. m. | | | 96 | 354.56 |
| 5.28 a. m. to 6.00 a. m. | 32 | 160.37 | | |
| 6.09 a. m. to 9.08 a. m. | 188 | 855.44 | | |
| 9.32 a. m. to 12.08 p. m. | | | 156 | 517.42 |
| 12.28 p. m. to 6.00 p. m. | 332 | 1,534.39 | | |
| 6.00 p. m. to 8.36 p. m. | 156 | 706.59 | | |
| 9.00 p. m. to 11.40 p. m. | | | 160 | 576.37 |
| 12.20 a. m. to 12.56 a. m. | 36 | 193.26 | | |
| 1.20 a. m. to 3.56 a. m. | | | 156 | 581.78 |
| 4.16 a. m. to 6.00 a. m. | 104 | 525.58 | | |
| 6.00 a. m. to 8.16 a. m. | 136 | 619.10 | | |
| 8.40 a. m. to 11.16 a. m. | | | 156 | 521.91 |
| 11.36 a. m. to 1.48 p. m. | 132 | 637.78 | | |
| 2.12 p. m. to 3.56 p. m. | | | 104 | 350.52 |
| 4.16 p. m. to 6.00 p. m. | 104 | 511.67 | | |
| Totals | 1,500 | 6,998.37 | 1,004 | 3,551.35 |
| Total corrections for capacity, feed, water, excreta, etc | | −36.88 | | −45.62 |
| | | 6,961.49 | | 3,505.73 |
| Heat per minute | | 4.6410 | | 3.4918 |
| Steer B: | | | | |
| 6.00 p. m. to 9.24 p. m. | 204 | 830.14 | | |
| 9.48 p. m. to 11.32 p. m. | | | 104 | 318.23 |
| 11.52 p. m. to 1.40 a. m. | 108 | 509.92 | | |
| 2.04 a. m. to 5.32 a. m. | | | 208 | 661.71 |
| 6.00 a. m. to 10.16 a. m. | 256 | 1,067.24 | | |
| 10.40 a. m. to 11.48 a. m. | | | 68 | 192.69 |
| 12.08 p. m. to 2.44 p. m. | 156 | 695.19 | | |
| 3.12 p. m. to 3.28 p. m. | | | 16 | 44.41 |
| 3.28 p. m. to 5.12 p. m. | | | 104 | 300.17 |
| 5.32 p. m. to 6.00 p. m. | 28 | 113.06 | | |
| 6.00 p. m. to 9.16 p. m. | 196 | 838.40 | | |
| 9.40 p. m. to 11.12 p. m. | | | 92 | 286.32 |
| 11.32 p. m. to 12.28 a. m. | 56 | 266.96 | | |
| 12.52 a. m. to 2.40 a. m. | | | 108 | 337.26 |
| 3.00 a. m. to 4.12 a. m. | 72 | 346.48 | | |
| 4.36 a. m. to 5.28 a. m. | | | 52 | 173.46 |
| 5.48 a. m. to 6.00 a. m. | 12 | 43.94 | | |
| 6.00 a. m. to 7.40 a. m. | 100 | 432.93 | | |
| 8.04 a. m. to 9.52 a. m. | | | 108 | 312.18 |
| 10.12 a. m. to 11.56 a. m. | 104 | 460.65 | | |
| 12.32 p. m. to 3.16 p. m. | | | 164 | 505.09 |
| 3.36 p. m. to 6.00 p. m. | 144 | 631.19 | | |
| Totals | 1,436 | 6,236.10 | 1,024 | 3,131.52 |
| Total corrections for capacity, feed, water, excreta, etc | | −57.18 | | +13.19 |
| | | 6,178.92 | | 3,144.71 |
| Heat per minute | | 4.3029 | | 3.0710 |
| *Period IV.* | | | | |
| Steer A: | | | | |
| 6.00 p. m. to 8.12 p. m. | 132 | 602.25 | | |
| 8.36 p. m. to 10.24 p. m. | | | 108 | 399.66 |
| 11.12 p. m. to 12.08 a. m. | 56 | 309.72 | | |
| 12.28 a. m. to 3.08 a. m. | | | 160 | 619.81 |
| 3.28 a. m. to 3.56 a. m. | 28 | 152.94 | | |
| 6.12 a. m. to 8.04 a. m. | 112 | 566.37 | | |
| 8.28 a. m. to 10.52 a. m. | | | 144 | 521.01 |
| 11.12 a. m. to 12.04 p. m. | 52 | 281.05 | | |
| 12.52 p. m. to 1.08 p. m. | 16 | 81.23 | | |
| 1.28 p. m. to 2.28 p. m. | | | 60 | 217.58 |
| 2.40 p. m. to 3.08 p. m. | 28 | 148.19 | | |
| 3.52 p. m. to 5.08 p. m. | | | 76 | 283.73 |
| 5.44 p. m. to 6.00 p. m. | 16 | 84.05 | | |
| 6.20 p. m. to 8.28 p. m. | 128 | 662.69 | | |

TABLE 142.—*Heat emitted by radiation and conduction during periods of standing and lying, 1906*—Continued.

| Periods. | Standing. |  | Lying. |  |
|---|---|---|---|---|
|  | Elapsed time. | Total heat. | Elapsed time. | Total heat. |
| *Period IV*—Continued. |  |  |  |  |
| Steer A—Continued. | *Minutes.* | *Calories.* | *Minutes.* | *Calories.* |
| 8.48 p. m to 12.00 a. m |  |  | 192 | 753.22 |
| 12.20 a. m to 1.24 a. m | 64 | 373.80 |  |  |
| 2.00 a. m to 3.04 a. m |  |  | 64 | 253.75 |
| 3.24 a. m to 4.32 a. m | 68 | 365.21 |  |  |
| 4.52 a. m. to 6.00 a. m | 68 | 335.99 |  |  |
| 6.00 a. m. to 7.12 a. m | 72 | 331.66 |  |  |
| 7.32 a. m. to 8.56 a. m |  |  | 84 | 290.03 |
| 9.16 a. m. to 9.48 a. m | 32 | 166.64 |  |  |
| 10.08 a. m. to 10.32 a. m |  |  | 24 | 84.95 |
| 10.52 a. m. to 11.44 a. m | 52 | 272.66 |  |  |
| 12.20 p. m. to 2.52 p. m |  |  | 152 | 548.02 |
| 4.24 p. m. to 6.00 p. m | 96 | 488.67 |  |  |
| Totals | 1,020 | 5,223.12 | 1,064 | 3,971.76 |
| Total corrections for capacity, feed, water, excreta, etc |  | +97.81 |  | −52.63 |
|  |  | 5,220.93 |  | 3,919.13 |
| Heat per minute |  | 5.2166 |  | 3.6834 |
| Steer B: |  |  |  |  |
| 6.00 p. m. to 7.04 p. m | 64 | 275.22 |  |  |
| 7.24 p. m. to 8.36 p. m |  |  | 72 | 241.86 |
| 10.00 p. m. to 12.00 a. m |  |  | 120 | 459.90 |
| 12.36 a. m. to 1.00 a. m | 24 | 128.45 |  |  |
| 1.28 a. m. to 4.52 a. m |  |  | 204 | 752.00 |
| 5.20 a. m. to 6.00 a. m | 40 | 213.45 |  |  |
| 6.00 a. m. to 7.20 a. m | 80 | 374.17 |  |  |
| 8.00 a. m. to 10.16 a. m |  |  | 136 | 441.72 |
| 11.28 a. m to 1.24 p. m |  |  | 116 | 398.73 |
| 1.44 p. m. to 2.08 p. m | 24 | 122.15 |  |  |
| 2.48 p. m. to 4.52 p. m |  |  | 124 | 446.59 |
| 5.04 p. m. to 5.18 p. m | 14 | 71.87 |  |  |
| 5.18 p. m. to 5.38 p. m | 20 | 103.19 |  |  |
| 5.42 p. m. to 6.00 p. m | 18 | 90.92 |  |  |
| 6.00 p. m. to 6.32 p. m | 32 | 164.12 |  |  |
| 6.32 p. m. to 7.08 p. m | 36 | 178.35 |  |  |
| 7.28 p/m. to 8.07 p. m |  |  | 39 | 157.10 |
| 8.07 p. m. to 9.08 p. m |  |  | 61 | 215.94 |
| 9.48 p. m. to 1.12 a. m |  |  | 204 | 769.86 |
| 1.56 a. m. to 4.20 a. m |  |  | 144 | 555.98 |
| 5.44 a. m. to 6.00 a. m | 16 | 78.09 |  |  |
| 6.00 a. m. to 7.48 a. m | 108 | 497.66 |  |  |
| 8.16 a. m. to 8.56 a. m |  |  | 40 | 125.20 |
| 9.16 a. m. to 9.40 a. m | 24 | 116.25 |  |  |
| 10.00 a. m. to 2.04 p. m |  |  | 244 | 813.15 |
| 2.16 p. m. to 2 38 p. m | 32 | 158.44 |  |  |
| 2.38 p. m. to 3.14 p. m | 36 | 172.60 |  |  |
| 3.36 p. m. to 5.12 p. m |  |  | 96 | 342.37 |
| 5.40 p. m. to 6.00 p. m | 20 | 96.11 |  |  |
| Totals | 588 | 2,841.04 | 1,600 | 5,720.40 |
| Total corrections for capacity, feed, water, excreta, etc |  | +94.19 |  | −95.12 |
|  |  | 2,935.23 |  | 5,625.28 |
| Heat per minute |  | 4.9919 |  | 3.5158 |

TABLE 143.—*Average heat per minute emitted by radiation and conduction, 1906.*

| Periods. | Standing. | Lying. |
|---|---|---|
| *Steer A.* | *Calories.* | *Calories.* |
| I | 5.7323 | 4.2716 |
| II | 7.5469 | 5.2249 |
| III | 4.6410 | 3.4918 |
| IV | 5.2166 | 3.6834 |
| *Steer B.* |  |  |
| I | 5.3824 | 3.8850 |
| II | 6.1683 | 4.2709 |
| III | 4.3029 | 3.0710 |
| IV | 4.9919 | 3.5158 |

### HEAT GIVEN OFF AS LATENT HEAT OF WATER VAPOR.

On the basis of the discussion on pages 122 to 124, it is assumed that the percentage of the total heat emitted which was given off as latent heat of water vapor was independent of the standing or lying of the animal.

### HEAT EMISSION AND PRODUCTION COMPUTED TO 12 HOURS STANDING.

With the exception of steer B in Period IV, the time spent standing did not vary greatly from 12 hours, and consequently the correction, computed as in the previous year's experiments (see p. 43), is comparatively small. The following are the final results of the computation:

TABLE 144.—*Heat production corrected to 12 hours standing, 1906.*

| Periods. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Corrected total heat emission. | Correction for gain or loss of matter by body. | Corrected total heat production. | Corrected total heat emission. | Correction for gain or loss of matter by body. | Corrected total heat production. |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| I | 9,305.0 | − 31.1 | 9,273.9 | 8,986.9 | +28.8 | 9,015.7 |
| II | 12,599.2 | − 85.7 | 12,513.5 | 9,971.3 | −61.9 | 9,909.4 |
| III | 7,291.7 | − 46.3 | 7,245.4 | 6,724.2 | +54.1 | 6,778.3 |
| IV | 8,285.7 | −100.2 | 8,185.5 | 7,836.1 | + 1.0 | 7,837.1 |

### AVAILABILITY OF METABOLIZABLE ENERGY.

By substituting the foregoing corrected values for the heat production in the balances of energy contained in Table 136, we obtain the corresponding corrected values for the gains of energy by the animals, as follows:

TABLE 145.—*Corrected gains of energy by the animals, 1906.*

| Periods. | Steer A. | | Steer B. | |
|---|---|---|---|---|
| | Income. | Outgo. | Income. | Outgo. |
| Period I: | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Metabolizable | 10,720.7 | | 8,502.3 | |
| Brushings | | 103.8 | | 89.4 |
| Heat (from Table 144) | | 9,273.9 | | 9,015.7 |
| Gain | | 1,343.0 | 602.8 | |
| | 10,720.7 | 10,720.7 | 9,105.1 | 9,105.1 |
| Period II: | | | | |
| Metabolizable | 17,290.3 | | 10,922.1 | |
| Brushings | | 103.8 | | 89.4 |
| Heat (from Table 144) | | 12,513.5 | | 9,909.4 |
| Gain | | 4,673.0 | | 923.3 |
| | 17,290.3 | 17,290.3 | 10,922.1 | 10,922.1 |
| Period III: | | | | |
| Metabolizable | 4,938.8 | | 4,751.2 | |
| Brushings | | 103.8 | | 89.4 |
| Heat (from Table 144) | | 7,245.4 | | 6,778.3 |
| Gain | 2,410.4 | | 2,116.5 | |
| | 7,349.2 | 7,349.2 | 6,867.7 | 6,867.7 |
| Period IV: | | | | |
| Metabolizable | 7,981.4 | | 7,100.0 | |
| Brushings | | 103.8 | | 89.4 |
| Heat (from Table 144) | | 8,185.5 | | 7,837.1 |
| Gain | 307.9 | | 826.5 | |
| | 8,289.3 | 8,289.3 | 7,926.5 | 7,926.5 |

From the data of the foregoing table, the percentage availability of the metabolizable energy of the hay and of the mixed grain may be computed in the same manner as in the experiments of 1905 (pp. 126–128). The corrections for live weight are based on the averages of the last six weighings of each period, as follows:

TABLE 146.—*Average live weights in calorimeter periods, 1906.*

| Periods. | Steer A. | Steer B. |
|---|---|---|
| | *Kilos.* | *Kilos.* |
| I | 404.0 | 298.0 |
| II | 420.7 | 309.6 |
| III | 399.1 | 296.2 |
| IV | 406.6 | 308.6 |

TIMOTHY HAY.

The availability of the metabolizable energy of the hay may be computed from the results of Periods III and IV, making the necessary correction for live weight, as follows:

TABLE 147.—*Availability of metabolizable energy of timothy hay, 1906.*

| Steer A—Periods IV-III. | Steer B—Periods IV-III. |
|---|---|
| $n=\left(\frac{399.1}{406.6}\right)^{2/3}=0.9879$ | $n=\left(\frac{296.2}{308.6}\right)^{2/3}=0.9729$ |
| $x_3=4{,}938.8 \quad y_3=-2{,}410.4$ | $x_3=4{,}751.2 \quad y_3=-2{,}116.5$ |
| $x_4=7{,}981.4 \quad y_4=-\ 307.9$ | $x_4=7{,}100.0 \quad y_4=-\ 826.5$ |
| $m=\frac{-2{,}410.4-(0.9879\times-307.9)}{4938.8-(0.9879\times7{,}981.4)}=71.49$ per cent. | $m=\frac{-2{,}116.5-(0.9729\times-826.5)}{4{,}751.2-(0.9729\times7{,}100.0)}=60.86$ per cent. |

MIXED GRAIN.

The following tables show the corrections for the variations in the amount of hay consumed in Periods I and II, on the mixed rations, and the availability of the metabolizable energy of the mixed grain, computed in the same manner as in the experiments of 1905.

TABLE 148.—*Correction for differences in amounts of hay eaten, 1906.*

| Periods. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Organic matter of hay. | Metabolizable energy of total ration. | Gain by animal. | Organic matter of hay. | Metabolizable energy of total ration. | Gain by animal. |
| | *Grams.* | *Calories.* | *Calories.* | *Grams.* | *Calories.* | *Calories.* |
| Period III | 2,493.1 | | | 2,326.5 | | |
| Period I | 2,459.0 | 10,720.7 | 1,343.0 | 2,294.2 | 8,502.3 | −602.8 |
| Correction | 34.1 | 66.2 | 47.3 | 32.3 | 64.8 | 39.4 |
| Period I corrected | 2,493.1 | 10,786.9 | 1,390.3 | 2,326.5 | 8,567.1 | −563.4 |
| Period III | 2,493.1 | | | 2,326.5 | | |
| Period II | 2,487.5 | 17,290.3 | 4,673.0 | 2,320.2 | 10,922.1 | 923.3 |
| Correction | 5.6 | 10.9 | 7.8 | 6.3 | 12.6 | 7.7 |
| Period II corrected | 2,493.1 | 17,301.2 | 4,680.8 | 2,326.5 | 10,934.7 | 931.0 |

TABLE 149.—*Availability of metabolizable energy of mixed grain, 1906.*

| Steer A—Periods I-III. | Steer B—Periods I-III. |
|---|---|
| $n=\left(\frac{399.1}{404.0}\right)^{2/3}=0.9199$<br>$x_3=4{,}938.8$ $y_3=-2{,}410.4$<br>$x_1=10{,}786.9$ $y_1=1{,}390.3$<br>$m=\frac{-2{,}410.4-(0.9199\times 1{,}390.3)}{4{,}938.3-(0.9199\times 10{,}786.9)}=74.02$ per cent. | $n=\left(\frac{296.2}{298.0}\right)^{2/3}=0.9961$<br>$x_3=4{,}751.2$ $y_3=-2{,}116.5$<br>$x_1=8{,}567.1$ $y_1=-563.4$<br>$m=\frac{-2{,}116.5-(0.9961\times -563.4)}{4{,}751.2-(0.9961\times 8{,}567.1)}=41.12$ per cent. |
| **Steer A—Periods II-III.** | **Steer B—Periods II-III.** |
| $n=\left(\frac{399.1}{420.7}\right)^{2/3}=0.9656$<br>$x_3=4{,}938.8$ $y_3=-2{,}410.4$<br>$x_2=17{,}301.2$ $y_2=4{,}680.8$<br>$m=\frac{-2{,}410.4-(0.9656\times 4{,}680.8)}{4{,}938.8-(0.9656\times 17{,}301.2)}=58.89$ per cent. | $n=\left(\frac{296.2}{309.6}\right)^{2/3}=0.9707$<br>$x_3=4{,}751.2$ $y_3=-2{,}116.5$<br>$x_2=10{,}934.7$ $y_2=931.0$<br>$m=\frac{-2{,}116.5-(0.9707\times 931.0)}{4{,}751.2-(0.9707\times 10{,}934.7)}=51.51$ per cent. |
| **Steer A—Periods II-I.** | **Steer B—Periods II-I.** |
| $n=\left(\frac{404.0}{420.7}\right)^{2/3}=0.9734$<br>$x_1=10{,}786.9$ $y_1=1{,}390.3$<br>$x_2=17{,}301.2$ $y_2=4{,}680.8$<br>$m=\frac{1{,}390.3-(0.9734\times 4{,}680.8)}{10{,}786.9-(0.9734\times 17{,}301.2)}=52.30$ per cent. | $n=\left(\frac{298.0}{309.6}\right)^{2/3}=0.9744$<br>$x_1=8{,}567.1$ $y_1=-563.4$<br>$x_2=10{,}934.7$ $y_2=931.0$<br>$m=\frac{-563.4-(0.9744\times 931.0)}{8{,}567.1-(0.9744\times 10{,}934.7)}=70.44$ per cent. |

TABLE 150.—*Summary of percentage availability of metabolizable energy, 1906.*

| | Steer A. | Steer B. |
|---|---|---|
| | *Per cent.* | *Per cent.* |
| Timothy hay: | | |
| Periods III and IV | 71.49 | 60.86 |
| Mixed grain: | | |
| Periods I and III | 74.02 | 41.12 |
| Periods II and I | 52.30 | 70.44 |
| Periods II and III | 58.89 | 51.51 |

The foregoing results are also represented graphically in figure 8 of Part I (p. 48).

## RESPIRATION CALORIMETER EXPERIMENTS OF 1907.

These were substantially a repetition of the experiments of the previous year, the amount of feed given being increased to correspond to the increased weight of the animals.

### FEEDING STUFFS.

*Hay.*—The hay was very nearly pure timothy, grown upon the experiment station farm and harvested about the last of June or the first of July in unusually good condition. No clover was noticed when handling the hay. The hay was cut and sampled on December

18 and 19, 1906, duplicate samples being taken for analysis and the remainder stored as in the previous year. Table 151 shows the composition of the two general samples and also of the four taken during the progress of the experiments.

TABLE 151.—*Composition of dry matter of timothy hay, 1907.*

| Components and energy. | General samples. | | | Samples taken during experiment. | | | |
|---|---|---|---|---|---|---|---|
| | A. | B. | Average. | Period I. | Period II. | Period III. | Period IV. |
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Ash | 5.110 | 4.915 | 5.013 | 4.973 | 4.956 | 4.978 | 5.115 |
| Protein [1] | 7.094 | 6.700 | 6.897 | 6.850 | 6.419 | 6.331 | 6.913 |
| Nonprotein [1] | 0.244 | 0.244 | 0.244 | 0.428 | 0.597 | 0.691 | 0.423 |
| Crude fiber | 30.675 | 31.619 | 31.147 | 30.930 | 31.170 | 31.114 | 29.980 |
| Nitrogen-free extract | 54.472 | 54.632 | 54.552 | 54.610 | 54.973 | 54.804 | 55.409 |
| Ether extract | 2.405 | 1.890 | 2.147 | 2.209 | 1.885 | 2.082 | 2.160 |
| | 100.000 | 100.000 | 100.000 | 100.000 | 100.000 | 100.000 | 100.000 |
| Total nitrogen | 1.187 | 1.124 | 1.155 | 1.187 | 1.154 | 1.160 | 1.196 |
| Protein nitrogen | 1.135 | 1.072 | 1.104 | 1.096 | 1.027 | 1.013 | 1.106 |
| Carbon | | | | 46.793 | 46.961 | 46.930 | 47.087 |
| Hydrogen | | | | 5.775 | 5.742 | 5.792 | 5.806 |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Energy per gram | | | | 4,493.4 | 4,497.5 | 4,509.3 | 4,520.8 |

[1] Computed from nitrogen, using factors stated in Part III, page 203.

*Grain.*—The same mixture of bran, corn meal, and old-process linseed meal was used as in the previous year and the sampling was done in the same way. Check analyses of samples of the mixed grain were also included. The results were as follows:

TABLE 152.—*Composition of dry matter of grain, 1907.*

| Components and energy. | Wheat bran. | | Corn meal. | | Linseed meal. | |
|---|---|---|---|---|---|---|
| | Period I. | Period II. | Period I. | Period II. | Period I. | Period II. |
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Ash | 7.156 | 7.019 | 1.495 | 1.477 | 5.816 | 5.811 |
| Protein [1] | 13.298 | 13.503 | 10.090 | 9.744 | 27.150 | 27.819 |
| Nonprotein [1] | 3.158 | 3.050 | 0.155 | 0.517 | 3.972 | 3.633 |
| Crude fiber | 10.400 | 10.060 | 2.220 | 2.061 | 8.810 | 8.840 |
| Nitrogen-free extract | 61.905 | 62.474 | 81.972 | 82.172 | 47.614 | 47.259 |
| Ether extract | 4.063 | 3.894 | 4.068 | 4.029 | 6.638 | [2] 6.638 |
| | 100.000 | 100.000 | 100.000 | 100.000 | 100.000 | 100.000 |
| Total nitrogen | 3.005 | 3.018 | 1.715 | 1.734 | 5.782 | 5.831 |
| Protein nitrogen | 2.333 | 2.369 | 1.682 | 1.624 | 4.937 | 5.058 |
| Carbon | 45.685 | 45.867 | 46.360 | 46.141 | 47.816 | 48.295 |
| Hydrogen | 5.954 | 5.995 | 6.247 | 6.153 | 6.049 | 5.948 |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Energy, per gram | 4.5789 | 4.5835 | 4.5348 | 4.5276 | 4.8010 | 4.8747 |

[1] Computed from nitrogen, using factors stated in Part III, page 203.
[2] Assumed same as Period I.

TABLE 153.—*Composition of dry matter of mixed grain.*

| Components and energy. | Period I. | | Period II. | |
|---|---|---|---|---|
| | Computed. | Composite sample. | Computed. | Composite sample. |
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Ash | 4.156 | 4.283 | 4.126 | 4.129 |
| Protein[1] | 17.861 | 18.215 | 18.030 | 18.763 |
| Nonprotein[1] | 2.220 | 1.889 | 2.214 | 2.120 |
| Crude fiber | 6.213 | 6.404 | 6.109 | 6.342 |
| Nitrogen-free extract | 64.378 | 63.775 | 64.393 | 63.461 |
| Ether extract | 5.172 | 5.434 | 5.128 | 5.185 |
| | 100.000 | 100.000 | 100.000 | 100.000 |
| Total nitrogen | 3.642 | 3.635 | 3.673 | 3.783 |
| Protein nitrogen | 3.170 | 3.233 | 3.202 | 3.332 |
| Carbon | 46.888 | 46.818 | 47.025 | 47.074 |
| Hydrogen | 6.120 | 6.467 | 6.043 | 5.827 |
| | *Calories.* | *Calories.* | *Calories.* | *Calories* |
| Energy per gram | 4.6552 | 4.6806 | 4.6843 | 4.6959 |

[1] Computed from nitrogen, using factors stated in Part III, page 208.

## PERIODS AND RATIONS.

The periods and rations are tabulated in the same manner as before, the dates being inclusive in all cases.

TABLE 154 —*Periods, 1907.*

| Periods. | Steer A. | | Steer B. | |
|---|---|---|---|---|
| | Preliminary feeding. | Excreta collected. | Preliminary feeding. | Excreta collected. |
| I | Jan. 20 to 30 | Jan. 31 to Feb. 9 | Jan. 27 to Feb. 6 | Feb. 7 to 16. |
| Transition | Feb. 10 to 16 | | Feb. 17 to 23 | |
| II | Feb. 17 to 27 | Feb. 28 to Mar. 9 | Feb. 24 to Mar. 6 | Mar. 7 to 16. |
| III | Mar. 10 to 20 | Mar. 21 to 30 | Mar. 17 to 27 | Mar. 28 to Apr. 6. |
| IV | Mar. 31 to Apr. 10 | Apr. 11 to 20 | Apr. 7 to 17 | Apr. 18 to 27. |

TABLE 155.—*Daily rations, 1907.*

| Periods. | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Timothy hay. | Wheat bran. | Corn meal. | Linseed meal. | Timothy hay. | Wheat bran. | Corn meal. | Linseed meal. |
| | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| I | 3,400 | 335 | 1,000 | 1,000 | 3,200 | 235 | 700 | 700 |
| II | 3,400 | 800 | 2,400 | 2,400 | 3,200 | 450 | 1,350 | 1,350 |
| III | 3,400 | | | | 3,200 | | | |
| IV | 5,600 | | | | 5,300 | | | |

## DIGESTIBILITY OF THE RATIONS.

The digestibility of the rations is computed from the figures in Tables IX and X of the appendix in the same manner as before with the following results.

TABLE 156.—*Feed and excreta—Period I, 1907.*

| | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of days. | Fresh weight. | Dry matter. | | Number of days. | Fresh weight. | Dry matter. | |
| | | *Grams.* | *Per cent.* | *Grams.* | | *Grams.* | *Per cent.* | *Grams.* |
| Timothy hay: | | | | | | | | |
| Total | 10 | 34,000.0 | 86.33 | 29,351.5 | 10 | 32,000.0 | 86.33 | 27,625.0 |
| Uneaten | | 2.5 | 86.33 | 2.2 | | 19.4 | 86.33 | 16.8 |
| Eaten | | 33,997.5 | | 29,349.5 | | 31,980.8 | | 27,608.2 |
| Eaten per day | | 3,399.8 | | 2,935.0 | | 3,198.1 | | 2,760.8 |
| Wheat bran: | | | | | | | | |
| Total | | 3,350.0 | 84.97 | 2,846.6 | 10 | 2,350.0 | 84.97 | 1,996.9 |
| Eaten per day | | 335.0 | | 284.7 | | 235.0 | | 199.7 |
| Corn meal: | | | | | | | | |
| Total | | 10,000.0 | 83.71 | 8,370.9 | 10 | 7,000.0 | 83.71 | 5,859.6 |
| Eaten per day | | 1,000.0 | | 837.1 | | 700.0 | | 586.0 |
| Linseed meal: | | | | | | | | |
| Total | 10 | 10,000.0 | 87.44 | 8,743.8 | 10 | 7,000.0 | 87.44 | 6,120.7 |
| Eaten per day | | 1,000.0 | | 874.4 | | 700.0 | | 612.1 |
| Feces: | | | | | | | | |
| Collected | | 84,590.0 | 18.12 | 15,323.5 | 10 | 60,950.0 | 23.14 | 14,105.1 |
| Spilled Feb. 7 | | 5.0 | 80.68 | 4.0 | | | | |
| In duct | | 616.9 | 21.77 | 134.3 | | 7.4 | 50.68 | 3.7 |
| Total | | 85,211.9 | | 15,461.8 | | 60,957.4 | | 14,108.8 |
| Excretion per day | | 8,521.2 | | 1,546.2 | | 6,095.7 | | 1,410.9 |

TABLE 157.—*Digestibility of rations—Period I, 1907.*

| | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract | Ether extract. | Total nitrogen. | Carbon. | Hydrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Steer A.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Calories.* |
| Timothy hay | 2,934.9 | 146.0 | 2,788.9 | 201.0 | 12.6 | 907.8 | 1,602.7 | 64.8 | 34.8 | 1,373.3 | 169.5 | 13,187.7 |
| Wheat bran | 284.7 | 20.4 | 264.3 | 37.9 | 8.9 | 29.6 | 176.2 | 11.6 | 8.6 | 130.1 | 17.0 | 1,303.6 |
| Corn meal | 837.1 | 12.5 | 824.6 | 84.5 | 1.3 | 18.6 | 686.2 | 34.1 | 14.4 | 388.1 | 52.3 | 3,796.1 |
| Linseed meal | 874.4 | 50.9 | 823.5 | 237.4 | 34.7 | 77.0 | 416.3 | 58.0 | 50.6 | 418.1 | 52.9 | 4,198.0 |
| Total | 4,931.1 | 229.8 | 4,701.3 | 560.8 | 57.5 | 1,033.0 | 2,881.4 | 168.5 | 108.4 | 2,309.6 | 291.7 | 22,485.4 |
| Feces | 1,546.2 | 149.6 | 1,396.6 | 206.9 | | 448.9 | 704.6 | 36.3 | 33.1 | 750.0 | 87.7 | 7,359.3 |
| Digested | 3,384.9 | 80.2 | 3,304.7 | 353.9 | 57.5 | 584.1 | 2,176.8 | 132.2 | 75.3 | 1,559.6 | 204.0 | 15,126.1 |
| Percentage digestibility | 68.64 | 34.90 | 70.29 | 63.09 | 100.00 | 56.54 | 75.55 | 78.46 | 69.46 | 67.53 | 69.93 | 67.27 |
| *Steer B.* | | | | | | | | | | | | |
| Timothy hay | 2,760.8 | 137.3 | 2,623.5 | 189.1 | 11.8 | 853.9 | 1,507.7 | 61.0 | 32.8 | 1,291.9 | 159.4 | 12,405.4 |
| Wheat bran | 199.7 | 14.3 | 185.4 | 26.6 | 6.3 | 20.8 | 123.6 | 8.2 | 6.0 | 91.2 | 11.9 | 914.4 |
| Corn meal | 586.0 | 8.8 | 577.2 | 59.1 | 0.9 | 13.0 | 480.4 | 23.8 | 10.0 | 271.7 | 36.6 | 2,657.4 |
| Linseed meal | 612.1 | 35.6 | 576.5 | 166.2 | 24.3 | 53.9 | 291.4 | 40.6 | 35.4 | 292.7 | 37.0 | 2,938.7 |
| Total | 4,158.6 | 196.0 | 3,962.6 | 441.0 | 43.3 | 941.6 | 2,403.1 | 133.6 | 84.2 | 1,947.5 | 244.9 | 18,915.9 |
| Feces | 1,410.9 | 135.9 | 1,275.0 | 152.8 | | 419.0 | 664.1 | 39.0 | 24.5 | 682.3 | 81.1 | 6,767.7 |
| Digested | 2,747.7 | 60.1 | 2,687.6 | 288.2 | 43.3 | 522.6 | 1,739.0 | 94.6 | 59.7 | 1,265.2 | 163.8 | 12,148.2 |
| Percentage digestibility | 66.07 | 30.66 | 67.82 | 65.35 | 100.00 | 55.50 | 72.36 | 70.80 | 70.90 | 64.97 | 66.88 | 64.22 |

TABLE 158.—*Feed and excreta—Period II, 1907.*

| | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of days. | Fresh weight. | Dry matter. | | Number of days. | Fresh weight. | Dry matter. | |
| | | *Grams.* | *Per cent.* | *Grams.* | | *Grams.* | *Per cent.* | *Grams.* |
| Timothy: | | | | | | | | |
| Total | 10 | 34,000.0 | 86.75 | 29,495.0 | 10 | 32,000.0 | 86.75 | 27,760.0 |
| Uneaten | ........ | 9.8 | 86.75 | 8.5 | ........ | 20.0 | 86.75 | 17.4 |
| Eaten | ........ | 33,990.2 | .......... | 29,486.5 | ........ | 31,980.0 | .......... | 27,742.6 |
| Eaten per day | ........ | 3,399.0 | .......... | 2,948.7 | ........ | 3,198.0 | .......... | 2,774.3 |
| Wheat bran: | | | | | | | | |
| Total | 10 | 8,000.0 | 83.78 | 6,702.5 | 10 | 4,500.0 | 83.78 | 3,770.2 |
| Eaten per day | ........ | 800.0 | .......... | 670.3 | ........ | 450.0 | .......... | 377.0 |
| Corn meal: | | | | | | | | |
| Total | ........ | 24,000.0 | 83.28 | 19,987.9 | 10 | 13,500.0 | 83.28 | 11,243.2 |
| Eaten per day | ........ | 2,400.0 | .......... | 1,998.8 | ........ | 1,350.0 | .......... | 1,124.3 |
| Linseed meal: | | | | | | | | |
| Total | ........ | 24,000.0 | 87.08 | 20,899.4 | 10 | 13,500.0 | 87.08 | 11,755.9 |
| Eaten per day | ........ | 2,400.0 | .......... | 2,089.9 | ........ | 1,350.0 | .......... | 1,175.6 |
| Feces: | | | | | | | | |
| Collected | ........ | 132,550.0 | 16.42 | 21,766.0 | ........ | 74,695.0 | 20.41 | 15,242.3 |
| Spilled Mar. 7 | ........ | 142.3 | 38.79 | 55.2 | ........ | .......... | .......... | .......... |
| Spilled Mar. 14 | ........ | .......... | .......... | .......... | ........ | 69.3 | 52.22 | 36.2 |
| In duct | ........ | 1,241.0 | 18.13 | 224.9 | ........ | 569.6 | 25.78 | 146.8 |
| Total | ........ | 133,933.3 | .......... | 22,046.1 | ........ | 75,333.9 | .......... | 15,425.3 |
| Excretion per day | ........ | 13,393.3 | .......... | 2,204.6 | ........ | 7,533.4 | .......... | 1,542.5 |

TABLE 159.—*Digestibility of rations—Period II, 1907.*

| | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Carbon. | Hydrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Steer A.* | | | | | | | | | | | | |
| | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Gms.* | *Calories.* |
| Timothy hay | 2,948.7 | 146.1 | 2,802.6 | 189.3 | 17.6 | 919.1 | 1,621.0 | 55.6 | 34.0 | 1,384.7 | 169.3 | 13,261.8 |
| Wheat bran | 670.2 | 47.0 | 623.2 | 90.5 | 20.4 | 67.4 | 418.7 | 26.1 | 20.2 | 307.4 | 40.2 | 3,071.9 |
| Corn meal | 1,998.8 | 29.5 | 1,969.3 | 208.0 | 10.3 | 41.2 | 1,642.5 | 80.5 | 34.7 | 922.3 | 123.0 | 9,049.8 |
| Linseed meal | 2,090.0 | 121.4 | 1,968.6 | 581.4 | 75.9 | 184.8 | 987.8 | [1]138.7 | 121.9 | 1,009.4 | 124.3 | 10,188.1 |
| Total | 7,707.7 | 344.0 | 7,363.7 | 1,069.2 | 124.2 | 1,212.5 | 4,670.0 | 300.9 | 210.8 | 3,623.8 | 456.8 | 35,571.6 |
| Feces | 2,204.6 | 229.0 | 1,975.6 | 343.8 | ...... | 656.5 | 927.1 | 48.2 | 55.0 | 1,049.3 | 124.4 | 10,340.7 |
| Digested | 5,503.1 | 115.0 | 5,388.1 | 725.4 | 124.2 | 556.0 | 3,742.9 | 252.7 | 155.8 | 2,574.5 | 332.4 | 25,230.9 |
| Percentage digestibility | 71.40 | 33.43 | 73.17 | 67.84 | 100.00 | 45.89 | 80.15 | 83.98 | 73.91 | 71.04 | 72.77 | 70.93 |
| *Steer B.* | | | | | | | | | | | | |
| Timothy hay | 2,774.3 | 137.5 | 2,636.8 | 178.1 | 16.6 | 864.7 | 1,525.1 | 52.3 | 32.0 | 1,302.8 | 159.3 | 12,477.4 |
| Wheat bran | 377.0 | 26.5 | 350.5 | 50.9 | 11.5 | 37.9 | 235.5 | 14.7 | 11.4 | 172.9 | 22.6 | 1,728.0 |
| Corn meal | 1,124.3 | 16.6 | 1,107.7 | 117.0 | 5.8 | 23.2 | 923.9 | 45.3 | 19.5 | 518.8 | 69.2 | 5,090.3 |
| Linseed meal | 1,175.6 | 68.3 | 1,107.3 | 327.0 | 42.7 | 103.9 | 555.6 | [1] 78.0 | 68.5 | 567.8 | 69.9 | 5,730.7 |
| Total | 5,451.2 | 248.9 | 5,202.3 | 673.0 | 76.6 | 1,029.7 | 3,240.1 | 190.3 | 131.4 | 2,562.3 | 321.0 | 25,026.4 |
| Feces | 1,542.5 | 154.4 | 1,385.1 | 205.1 | ...... | 459.0 | 685.2 | 38.8 | 32.8 | 737.5 | 84.5 | 7,371.1 |
| Digested | 3,908.7 | 94.5 | 3,814.2 | 467.9 | 76.6 | 570.7 | 2,554.9 | 151.5 | 98.6 | 1,824.8 | 236.5 | 17,655.3 |
| Percentage digestibility | 71.70 | 37.97 | 73.32 | 69.53 | 100.00 | 55.42 | 78.85 | 79.61 | 75.04 | 71.22 | 73.68 | 70.55 |

[1] Percentage of ether extract assumed to have been the same as in Period I.

TABLE 160.—*Feed and excreta—Period III, 1907.*

| | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of days. | Fresh weight. | Dry matter. | | Number of days. | Fresh weight. | Dry matter. | |
| Timothy hay: | | *Grams.* | *Per cent.* | *Grams.* | | *Grams.* | *Per cent.* | *Grams.* |
| Total | 10 | 34,000.0 | 87.49 | 29,745.6 | 10 | 32,000.0 | 87.49 | 27,995.8 |
| Uneaten | | 3.7 | 87.49 | 3.2 | | 15.1 | 87.49 | 13.2 |
| Eaten | | 33,996.3 | | 29,742.4 | | 31,984.9 | | 27,982.6 |
| Eaten per day | | 3,399.6 | | 2,974.2 | | 3,198.5 | | 2,798.3 |
| Feces: | | | | | | | | |
| Collected | | 50,165.0 | 21.97 | 11,021.8 | | 47,785.0 | 22.17 | 10,595.8 |
| Spilled Mar. 28 | | 64.0 | 48.55 | 31.1 | | | | |
| Spilled Apr. 4 | | | | | | 4.2 | 81.60 | 3.4 |
| In duct | | 176.8 | 33.14 | 58.6 | | 73.7 | 33.06 | 24.4 |
| Washings from duct | | 185.0 | 5.04 | 9.3 | | | | |
| Total | | 50,590.8 | | 11,120.8 | | 47,862.9 | | 10,623.6 |
| Excretion per day | | 5,059.1 | | 1,112.1 | | 4,786.3 | | 1,062.4 |

TABLE 161.—*Digestibility of rations—Period III, 1907.*

| | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Carbon. | Hydrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Steer A.* | *Grams.* | *Gms.* | *Grams.* | *Gms.* | *Gms.* | *Gms.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Gms.* | *Calories.* |
| Timothy hay | 2,974.2 | 148.1 | 2,826.1 | 188.3 | 20.6 | 925.3 | 1,630.0 | 61.9 | 34.5 | 1,395.8 | 172.3 | 13,411.6 |
| Feces | 1,112.1 | 89.3 | 1,022.8 | 111.3 | | 341.7 | 537.2 | 32.6 | 17.8 | 551.9 | 65.4 | 5,475.1 |
| Digested | 1,862.1 | 58.8 | 1,803.3 | 77.0 | 20.6 | 583.6 | 1,092.8 | 29.3 | 16.7 | 843.9 | 106.9 | 7,936.5 |
| Percentage digestibility | 62.61 | 39.70 | 63.81 | 40.89 | 100.00 | 63.07 | 67.04 | 47.33 | 48.41 | 60.46 | 62.04 | 59.18 |
| *Steer B.* | | | | | | | | | | | | |
| Timothy hay | 2,798.3 | 139.3 | 2,659.0 | 177.2 | 19.3 | 870.6 | 1,533.6 | 58.3 | 32.5 | 1,313.2 | 162.1 | 12,618.4 |
| Feces | 1,062.4 | 87.1 | 975.3 | 101.0 | | 312.3 | 529.6 | 32.4 | 16.2 | 527.9 | 60.8 | 5,247.0 |
| Digested | 1,735.9 | 52.2 | 1,683.7 | 76.2 | 19.3 | 558.3 | 1,004.0 | 25.9 | 16.3 | 785.3 | 101.3 | 7,371.4 |
| Percentage digestibility | 62.03 | 37.47 | 63.32 | 43.00 | 100.00 | 64.13 | 65.47 | 44.43 | 50.15 | 59.80 | 62.49 | 58.42 |

TABLE 162.—*Feed and excreta—Period IV, 1907.*

| | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of days. | Fresh weight. | Dry matter. | | Number of days. | Fresh weight. | Dry matter. | |
| Timothy hay: | | *Grams.* | *Per cent.* | *Grams.* | | *Grams.* | *Per cent.* | *Grams.* |
| Total | 10 | 56,000.0 | 87.37 | 48,925.0 | 10 | 53,000.0 | 87.37 | 46,304.0 |
| Uneaten | | 5.3 | 87.37 | 4.6 | | 6.3 | 87.37 | 5.5 |
| Eaten | | 55,994.7 | | 48,920.4 | | 53,993.7 | | 46,298.5 |
| Eaten per day | | 5,599.5 | | 4,892.0 | | 5,399.4 | | 4,629.9 |
| Feces: | | | | | | | | |
| Collected | | 99,655.0 | 18.79 | 18,725.2 | | 92,455.0 | 19.47 | 18,001.0 |
| Spilled Apr. 18 | | 27.6 | 68.46 | 18.9 | | | | |
| In duct | | 402.5 | 5.09 | 20.5 | | 18.8 | 90.46 | 17.0 |
| Total | | 100,088.1 | | 18,764.6 | | 92,473.8 | | 18,018.0 |
| Excretion per day | | 10,008.5 | | 1,876.5 | | 9,247.4 | | 1,801.8 |

TABLE 163.—*Digestibility of rations—Period IV, 1907.*

| | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Carbon. | Hydrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Steer A.*** | *Grams.* | *Gms.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Gms.* | *Calories.* |
| Timothy hay.. | 4,892.0 | 250.2 | 4,641.8 | 338.2 | 20.7 | 1,466.6 | 2,710.6 | 105.7 | 58.5 | 2,303.5 | 284.0 | 22,115.8 |
| Feces.......... | 1,876.9 | 154.2 | 1,724.4 | 184.4 | ...... | 548.4 | 935.5 | 54.5 | 29.5 | 931.8 | 108.9 | 9,236.8 |
| Digested... | 3,015.1 | 96.0 | 2,917.4 | 153.8 | 20.7 | 918.2 | 1,775.1 | 51.2 | 29.0 | 1,371.7 | 175.1 | 12,879.0 |
| Percentage digestibility... | 61.64 | 38.37 | 62.85 | 45.48 | 100.00 | 62.60 | 65.49 | 48.44 | 49.57 | 59.55 | 61.65 | 58.23 |
| ***Steer B.*** | | | | | | | | | | | | |
| Timothy hay.. | 4,629.8 | 236.8 | 4,393.0 | 320.1 | 19.6 | 1,388.0 | 2,565.3 | 100.0 | 55.4 | 2,180.0 | 268.8 | 20,930.4 |
| Feces.......... | 1,801.8 | 141.8 | 1,660.0 | 179.3 | ...... | 531.7 | 899.8 | 49.3 | 28.7 | 889.2 | 103.0 | 8,879.1 |
| Digested... | 2,828.0 | 95.0 | 2,733.0 | 140.8 | 19.6 | 856.3 | 1,665.5 | 50.7 | 26.7 | 1,290.8 | 165.8 | 12,051.3 |
| Percentage digestibility... | 61.02 | 40.12 | 62.21 | 43.99 | 100.00 | 61.69 | 64.92 | 50.70 | 48.19 | 59.21 | 61.68 | 57.58 |

## DIGESTIBILITY OF TIMOTHY HAY AND OF MIXED GRAIN.

From the data of Tables 156–163, the average digestibility of the timothy hay in Periods III and IV and the percentage digestibility of the mixed grains in Periods I and II are computed in the two following tables in the same manner as in the previous years:

TABLE 164.—*Average digestibility of timothy hay, 1907.*

| | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Carbon. | Hydrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Steer A.*** | | | | | | | | | | | | |
| | *Grams.* | *Gms.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Gms.* | *Calories.* |
| Fed in Period III.......... | 2,974.2 | 148.1 | 2,826.1 | 188.3 | 20.6 | 925.3 | 1,630.0 | 61.9 | 34.5 | 1,395.8 | 172.3 | 13,411.6 |
| Fed in Period IV.......... | 4,892.0 | 250.2 | 4,641.8 | 338.2 | 20.7 | 1,466.6 | 2,710.6 | 105.7 | 58.5 | 2,303.5 | 284.0 | 22,115.8 |
| Total ... | 7,866.2 | 398.3 | 7,467.9 | 526.5 | 41.3 | 2,391.9 | 4,340.6 | 167.6 | 93.0 | 3,699.3 | 456.3 | 35,527.4 |
| Digested in Period III... | 1,862.1 | 58.8 | 1,803.3 | 77.0 | 20.6 | 583.6 | 1,092.8 | 29.3 | 16.7 | 843.9 | 106.9 | 7,936.5 |
| Digested in Period IV... | 3,015.1 | 96.0 | 2,917.4 | 153.8 | 20.7 | 918.2 | 1,775.1 | 51.2 | 29.0 | 1,371.7 | 175.1 | 12,879.0 |
| Total ... | 4,877.2 | 154.8 | 4,720.7 | 230.8 | 41.3 | 1,501.8 | 2,867.9 | 80.5 | 45.7 | 2,215.6 | 282.0 | 20,815.5 |
| Percentage digestibility... | 62.00 | 38.87 | 63.21 | 43.84 | 100.00 | 62.79 | 66.07 | 48.03 | 49.14 | 59.89 | 61.80 | 58.59 |
| ***Steer B.*** | | | | | | | | | | | | |
| Fed in Period III.......... | 2,798.3 | 139.3 | 2,659.0 | 177.2 | 19.3 | 870.6 | 1,533.6 | 58.3 | 32.5 | 1,313.2 | 162.1 | 12,618.4 |
| Fed in Period IV.......... | 4,629.8 | 236.8 | 4,393.0 | 320.1 | 19.6 | 1,388.0 | 2,565.3 | 100.00 | 55.4 | 2,180.0 | 268.8 | 20,930.4 |
| Total ... | 7,428.1 | 376.1 | 7,052.0 | 497.3 | 38.9 | 2,258.6 | 4,098.9 | 158.3 | 87.9 | 3,493.2 | 430.9 | 33,548.8 |
| Digested in Period III... | 1,735.9 | 52.2 | 1,683.7 | 76.2 | 19.3 | 558.3 | 1,004.0 | 25.9 | 16.3 | 785.3 | 101.3 | 7,371.4 |
| Digested in Period IV... | 2,828.0 | 95.0 | 2,733.0 | 140.8 | 19.6 | 856.3 | 1,665.5 | 50.7 | 26.7 | 1,290.8 | 165.8 | 12,051.3 |
| Total ... | 4,563.9 | 147.2 | 4,416.7 | 217.0 | 38.9 | 1,414.6 | 2,669.5 | 76.6 | 43.0 | 2,076.1 | 267.1 | 19,422.7 |
| Percentage digestibility... | 61.44 | 39.14 | 62.63 | 43.64 | 100.00 | 62.63 | 65.13 | 48.39 | 48.92 | 59.43 | 61.99 | 57.89 |

TABLE 165.—*Computed digestibility of mixed grain, 1907.*

| | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Carbon. | Hydrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Steer A.* | | | | | | | | | | | | |
| Period I: | *Grams.* | *Gms.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Grams.* | *Gms.* | *Gms.* | *Grams.* | *Gms.* | *Calories.* |
| Total digested.... | 3,384.9 | 80.2 | 3,304.7 | 353.9 | 57.5 | 584.1 | 2,176.8 | 132.2 | 75.3 | 1,559.6 | 204.0 | 15,126.1 |
| Computed digestible in hay... | 1,819.6 | 56.8 | 1,762.9 | 88.1 | 12.6 | 570.0 | 1,058.9 | 31.1 | 17.1 | 822.5 | 104.8 | 7,726.7 |
| Digested from grain... | 1,565.3 | 23.4 | 1,541.8 | 265.8 | 44.9 | 14.1 | 1,117.9 | 101.1 | 58.2 | 737.1 | 99.2 | 7,399.4 |
| Total in grain..... | 1,996.2 | 83.8 | 1,912.4 | 359.8 | 44.9 | 125.2 | 1,278.7 | 103.7 | 73.6 | 936.3 | 122.2 | 9,297.7 |
| Percentage digestibility.... | 78.41 | 27.92 | 80.62 | 73.87 | 100.00 | 11.26 | 87.42 | 97.49 | 79.08 | 78.72 | 81.18 | 79.58 |
| | | | | | | 80.64 | | | | | | |
| Period II: | | | | | | | | | | | | |
| Total digested.... | 5,503.1 | 115.0 | 5,388.1 | 725.4 | 124.2 | 556.0 | 3,742.9 | 252.7 | 155.8 | 2,574.5 | 332.4 | 25,230.9 |
| Computed digestible in hay... | 1,828.2 | 56.8 | 1,771.5 | 83.0 | 17.6 | 577.1 | 1,071.0 | 26.7 | 16.7 | 829.3 | 104.6 | 7,770.1 |
| Digested from grain... | 3,674.9 | 58.2 | 3,616.6 | 642.4 | 106.6 | −21.1 | 2,671.9 | 226.0 | 139.1 | 1,745.2 | 227.8 | 17,460.8 |
| Total in grain..... | 4,759.0 | 197.9 | 4,561.1 | 879.9 | 106.6 | 293.2 | 3,049.0 | 245.3 | 176.8 | 2,239.1 | 287.5 | 22,309.8 |
| Percentage digestibility.... | 77.22 | 29.41 | 79.29 | 73.01 | 100.00 | −7.19 | 87.63 | 92.13 | 78.68 | 77.94 | 79.23 | 78.27 |
| | | | | | | 79.30 | | | | | | |
| *Steer B.* | | | | | | | | | | | | |
| Period I: | | | | | | | | | | | | |
| Total digested.... | 2,747.7 | 60.1 | 2,687.6 | 288.2 | 43.3 | 522.6 | 1,739.0 | 94.6 | 59.7 | 1,265.2 | 163.8 | 12,148.2 |
| Computed digestible in hay...... | 1,696.2 | 53.7 | 1,643.1 | 82.5 | 11.8 | −534.8 | 982.0 | 29.5 | 16.0 | 767.8 | 98.8 | 7,181.5 |
| Digested from grain... | 1,051.5 | 6.4 | 1,044.5 | 205.7 | 31.5 | −12.2 | 757.0 | 65.1 | 43.7 | 497.4 | 65.0 | 4,966.7 |
| Total in grain..... | 1,397.8 | 58.7 | 1,339.1 | 251.9 | 31.5 | 87.7 | 895.4 | 72.6 | 51.4 | 655.6 | 85.5 | 6,510.5 |
| Percentage digestibility.... | 75.23 | 10.90 | 78.02 | 81.66 | 100.00 | −13.91 | 84.54 | 89.67 | 85.02 | 75.87 | 76.02 | 76.29 |
| | | | | | | 75.76 | | | | | | |
| Period II: | | | | | | | | | | | | |
| Total digested.... | 3,908.7 | 94.5 | 3,814.2 | 467.9 | 76.6 | 570.7 | 2,554.9 | 151.5 | 98.6 | 1,824.8 | 236.5 | 17,655.3 |
| Computed digestible in hay...... | 1,704.5 | 53.8 | 1,651.4 | 77.7 | 16.6 | 541.6 | 993.3 | 25.3 | 15.7 | 774.3 | 98.8 | 7,223.2 |
| Digested from grain... | 2,204.2 | 40.7 | 2,162.8 | 390.2 | 60.0 | 29.1 | 1,561.6 | 126.2 | 82.9 | 1,050.5 | 137.7 | 10,432.1 |
| Total in grain..... | 2,676.9 | 111.4 | 2,565.5 | 494.9 | 60.0 | 165.0 | 1,715.0 | 138.0 | 99.4 | 1,259.5 | 161.7 | 12,549.0 |
| Percentage digestibility.... | 82.34 | 36.54 | 84.30 | 78.84 | 100.00 | 17.64 | 91.06 | 91.45 | 83.40 | 83.41 | 85.16 | 83.13 |
| | | | | | | 84.61 | | | | | | |

## URINARY EXCRETION.

The urine was collected, sampled, and analyzed as in the experiments of 1906, including daily determinations of nitrogen. The urinary excretion is tabulated in detail in Table IX of the appendix, and the results are summarized in the following tables in the same form as in the previous experiments:

TABLE 166.—*Results on urine (inclusive of wash water), 1907.*

|  | Weight. | Average specific gravity. | Total solids. |  | Total nitrogen. |  | Total carbon. |  | Total hydrogen. |  | Energy. |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |  |  |  |  | Per gram. | Total. |
| *Period I.* |  |  |  |  |  |  |  |  |  |  |  |  |
| Steer A: |  |  | *Per cent.* | *Grams.* | *Per cent.* | *Grams.* | *Per cent.* | *Grams.* | *Per cent.* | *Gms.* | *Calories.* | *Calories.* |
| Total collected..... | *Grams.*<br>42,440.0 | 1.0446 | 10.384 | 4,407.0 | 1.682 | 713.84 | 2.786 | 1,182.38 | 0.381 | 161.70 | 0.2814 | 11,942.6 |
| Spilled, Feb. 7..... | 975.0 | ...... | 5.464 | 53.3 | .885 | 8.63 | [1]1.466 | 14.29 | [1].200 | 1.95 | [1].1481 | 144.4 |
| Total..... | 43,415.0 | ...... | ...... | 4,460.3 | ...... | 722.47 | ...... | 1,196.67 | ...... | 163.65 | ...... | 12,087.0 |
| Daily average (10 days)..... | 4,341.5 | ...... | ...... | 446.0 | ...... | 72.25 | ...... | 119.67 | ...... | 16.37 | ...... | 1,208.7 |
| Steer B: |  |  |  |  |  |  |  |  |  |  |  |  |
| Total collected..... | 32,020.0 | 1.0501 | 12,366 | 3,959.2 | 1.820 | 582.76 | 3.360 | 1,075.87 | .466 | 149.21 | .3411 | 10,922.0 |
| Spilled, Feb. 16.... | 1,120.7 | ...... | 2.867 | 32.1 | .422 | 4.73 | [1].779 | 8.73 | [1].108 | 1.21 | [1].0791 | 88.6 |
| Total..... | 33,140.7 | ...... | ...... | 3,991.3 | ...... | 587.49 | ...... | 1,084.60 | ...... | 150.42 | ...... | 11,010.6 |
| Daily average (10 days)..... | 3,314.1 | ...... | ...... | 399.1 | ...... | 58.75 | ...... | 108.46 | ...... | 15.04 | ...... | 1,101.1 |
| *Period II.* |  |  |  |  |  |  |  |  |  |  |  |  |
| Steer A: |  |  |  |  |  |  |  |  |  |  |  |  |
| Total collected..... | 81,030.0 | 1.0322 | 9.433 | 7,643.6 | 1.847 | 1,496.62 | 2.329 | 1,887.19 | .419 | 339.52 | .2415 | 19,568.7 |
| Spilled, Mar. 5..... | 270.4 | ...... | 11.149 | 30.2 | 2.183 | 5.90 | [1]2.753 | 7.44 | [1].495 | 1.34 | .2854 | 77.2 |
| Total..... | 81,300.4 | ...... | ...... | 7,673.80 | ...... | 1,502.52 | ...... | 1,894.63 | ...... | 340.86 | ...... | 19,645.9 |
| Daily average (10 days)..... | 8,130.0 | ...... | ...... | 767.4 | ...... | 150.25 | ...... | 189.46 | ...... | 34.09 | ...... | 1,964.6 |
| Steer B: |  |  |  |  |  |  |  |  |  |  |  |  |
| Total collected..... | 37,785.0 | 1.0518 | 13.392 | 5,060.2 | 2.291 | 865.65 | 3.774 | 1,426.01 | .577 | 218.02 | .3844 | 14,524.6 |
| Spilled, Mar. 10.... | 269.6 | ...... | 12.602 | 34.0 | 2.156 | 5.81 | [1]3.552 | 9.58 | .543 | 1.47 | .3617 | 97.5 |
| Spilled, Mar. 15.... | 102.2 | ...... | 7.307 | 7.5 | 1.250 | 1.28 | [1]2.059 | 2.10 | .315 | .32 | .2097 | 21.4 |
| Spilled, Mar. 16.... | 173.2 | ...... | 1.058 | 1.8 | .181 | .31 | [1].298 | .52 | [1].046 | .08 | .0304 | 5.3 |
| Total..... | 38,330.0 | ...... | ...... | 5,103.5 | ...... | 873.05 | ...... | 1,438.21 | ...... | 219.89 | ...... | 14,648.8 |
| Daily average..... | 3,833.0 | ...... | ...... | 510.4 | ...... | 87.31 | ...... | 143.82 | ...... | 21.99 | ...... | 1,464.9 |
| *Period III.* |  |  |  |  |  |  |  |  |  |  |  |  |
| Steer A: |  |  |  |  |  |  |  |  |  |  |  |  |
| Total collected..... | 60,035.0 | 1.0292 | 6.710 | 4,028.4 | .490 | 293.85 | 1.176 | 706.01 | .182 | 109.26 | .1109 | 6,657.9 |
| Daily average (9 days)..... | 6,670.55 | ...... | ...... | 447.6 | ...... | 32.65 | ...... | 78.45 | ...... | 12.14 | ...... | 739.8 |

[1] Assumed to be proportional to nitrogen content.

TABLE 166.—*Results on urine (inclusive of wash water), 1907*—Continued.

| | Weight. | Average specific gravity. | Total solids. | | Total nitrogen. | | Total carbon. | | Total hydrogen. | | Energy. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Per gram. | Total. |
| *Period III*—Con. | | | | | | | | | | | | |
| Steer B: | *Grams.* | | *Per cent.* | *Grams.* | *Per cent.* | *Grams.* | *Per cent.* | *Grams.* | *Per cent.* | *Gms.* | *Calories.* | *Calories.* |
| Total collected..... | 39,195.0 | 1.0395 | 9.265 | 3,631.4 | .725 | 284.00 | 1.932 | 757.25 | .285 | 111.71 | .1860 | 7,290.3 |
| Spilled, Mar. 28.... | 188.8 | ...... | 1.866 | 3.5 | .146 | .28 | [1].389 | .73 | [1].057 | .11 | [1].0375 | 7.1 |
| Spilled, Mar. 28[2]... | 50.0 | ...... | 11.679 | 5.8 | .914 | .46 | 2.436 | 1.22 | [1].359 | .18 | .2345 | 11.7 |
| Total...... | 39,433.8 | ...... | ...... | 3,640.7 | ...... | 284.74 | ...... | 759.20 | ...... | 112.00 | ...... | 7,309.1 |
| Daily average (10 days)..... | 3,943.4 | ...... | ...... | 364.1 | ...... | 28.47 | ...... | 75.92 | ...... | 11.20 | ...... | 730.9 |
| *Period IV.* | | | | | | | | | | | | |
| Steer A: | | | | | | | | | | | | |
| Total collected..... | 61,415.0 | 1.0354 | 8.240 | 5,060.6 | .466 | 286.19 | 1.757 | 1,079.06 | .239 | 146.78 | .1605 | 9,857.1 |
| Spilled, Apr. 11.... | 226.5 | ...... | 1.390 | 3.2 | .079 | .18 | [1].298 | .67 | [1].041 | .09 | [1].0272 | 6.2 |
| Total...... | 61,641.5 | ...... | ...... | 5,063.8 | ...... | 286.37 | ...... | 1,079.73 | ...... | 146.87 | ...... | 9,863.3 |
| Daily average (10 days)..... | 6,164.2 | ...... | ...... | 506.4 | ...... | 28.64 | ...... | 107.97 | ...... | 14.69 | ...... | 986.3 |
| Steer B: | | | | | | | | | | | | |
| Total collected..... | 55,225.0 | 1.0410 | 8.434 | 4,657.7 | .447 | 246.86 | 1.707 | 942.69 | .236 | 130.33 | .1601 | 8,841.5 |
| Daily average (9 days)..... | 6,136.1 | ...... | ...... | 517.5 | ...... | 27.43 | ...... | 104.74 | ...... | 14.48 | ...... | 982.4 |

[1] Assumed to be proportional to nitrogen content.

[2] Estimated.

TABLE 167.—*Average daily excretion in urine, 1907.*

| Period. | Nitrogen. | Carbon. | Energy. | |
|---|---|---|---|---|
| | | | Total. | Per gram carbon. |
| *Steer A.* | *Grams.* | *Grams.* | *Calories.* | *Calories.* |
| I.......... | 72.25 | 119.67 | 1,208.7 | 10.10 |
| II.......... | 150.25 | 189.46 | 1,964.6 | 10.37 |
| III.......... | 32.65 | 78.45 | 739.8 | 9.43 |
| IV.......... | 28.64 | 107.97 | 986.3 | 9.13 |
| *Steer B.* | | | | |
| I.......... | 58.75 | 108.46 | 1,101.1 | 10.15 |
| II.......... | 87.31 | 143.82 | 1,464.9 | 10.19 |
| III.......... | 28.47 | 75.92 | 730.9 | 9.63 |
| IV.......... | 27.43 | 104.74 | 982.4 | 9.38 |

## PRODUCTION OF EPIDERMAL TISSUE.

Steer A was clipped on January 7 before beginning the experiments and at their close on May 7, and steer B on January 8 and May 6. The brushings of the animals were collected as in the previous year. The results of these determinations are contained in the following tables:

TABLE 168.—*Weights and composition of brushings for the two days in the calorimeter, 1907.*

| Components and energy. | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Period I. | Period II. | Period III. | Period IV. | Period I. | Period II. | Period III. | Period IV. |
| Weight.......grams.. | 35.1 | 62.7 | 39.6 | 42.3 | 45.9 | 52.7 | 39.7 | Lost. |
| Dry matter.per cent.. | 95.647 | 93.991 | 90.962 | 94.382 | 85.875 | 96.128 | 94.765 | .......... |
| Weight of dry matter.........grams.. | 33.57 | 58.93 | 36.02 | 39.92 | 39.42 | 50.66 | 37.62 | .......... |
| In dry matter: | | | | | | | | |
| Nitrogen— | | | | | | | | |
| Percentage....... | 5.408 | 5.308 | 5.446 | 6.643 | 4.059 | 5.197 | 6.347 | .......... |
| Weight ..grams.. | 1.82 | 3.13 | 1.96 | 2.65 | 1.60 | 2.63 | 2.39 | .......... |
| Carbon— | | | | | | | | |
| Percentage....... | 39.083 | 40.412 | 41.584 | 41.984 | 37.156 | 40.355 | 41.120 | .......... |
| Weight ..grams.. | 13.12 | 23.81 | 14.98 | 16.76 | 14.65 | 20.44 | 15.47 | .......... |
| Hydrogen— | | | | | | | | |
| Percentage....... | 4.833 | 5.244 | 5.340 | 5.457 | 4.677 | 5.213 | 5.335 | .......... |
| Weight ..grams.. | 1.62 | 3.09 | 1.92 | 2.18 | 1.84 | 2.64 | 2.01 | .......... |
| Energy— | | | | | | | | |
| Per gram, calories.. | 4.4298 | 4.5842 | 4.5951 | 4.7393 | 4.2212 | 4.5496 | 4.6251 | .......... |
| Total......do.... | 148.7 | 270.2 | 165.5 | 189.2 | 166.4 | 230.5 | 174.0 | .......... |

TABLE 169.—*Weights and composition of hair, 1907.*

| Components and energy. | Steer A. | Steer B. |
|---|---|---|
| Number of days.................................................. | 120 | 118 |
| Weight................................................grams.. | 770 | 607 |
| Dry matter..........................................per cent.. | 79.333 | 83.437 |
| Dry matter............................................grams.. | 610.86 | 506.46 |
| Daily average..........................................do.... | 5.09 | 4.29 |
| In dry matter: | | |
| Nitrogen— | | |
| Percentage.................................................. | 13.727 | 14.624 |
| Weight................................................grams.. | 83.85 | 74.06 |
| Daily average..........................................do.... | .70 | .63 |
| Carbon— | | |
| Percentage.................................................. | 47.796 | 48.157 |
| Weight................................................grams.. | 291.97 | 243.90 |
| Daily average..........................................do.... | 2.43 | 2.07 |
| Hydrogen— | | |
| Percentage.................................................. | 5.960 | 6.280 |
| Weight................................................grams.. | 36.53 | 31.81 |
| Daily average..........................................do.... | .304 | .270 |
| Energy— | | |
| Per gram...........................................calories.. | 5.1673 | 5.2993 |
| Total..................................................do.... | 3,156.5 | 2,683.9 |
| Daily average..........................................do.... | 26.3 | 22.7 |

TABLE 170.—*Average daily production of epidermal tissue, 1907.*

| Components and energy. | Steer A. | Steer B. |
|---|---|---|
| Dry matter............................................grams.. | 26.15 | 25.58 |
| Nitrogen...............................................do.... | 1.90 | 1.74 |
| Carbon.................................................do.... | 11.02 | 10.50 |
| Hydrogen...............................................do.... | 1.40 | 1.85 |
| Energy..............................................calories.. | 123.0 | 117.9 |

## DETERMINATION OF RESPIRATORY PRODUCTS.

The respiratory products were determined upon two consecutive days of each period as in the previous year with the results shown in Table 172. In the combustible gases given off by the animals the ratio of hydrogen to carbon was as follows:

TABLE 171.—*Ratio of hydrogen to carbon in combustible gases, 1907.*

| Periods. | Steer A, 1 : | Steer B, 1 : |
|---|---|---|
| I | 3.114 | 3.110 |
| II | 8.059 | 3.076 |
| III | 3.168 | 3.158 |
| IV | 3.121 | 3.106 |

TABLE 172.—*Carbon and hydrogen in gaseous excreta, 1907.*

| Periods. | In $CO_2$ and $H_2O$. |  | In hydrocarbons. |  | $CH_4$ computed from C. | H : C in hydrocarbon. |
|---|---|---|---|---|---|---|
|  | Carbon. | Hydrogen. | Carbon. | Hydrogen. |  |  |
| *Period I.* |  |  |  |  |  |  |
| Steer A, Feb. 6 and 7: | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | 1 : |
| Subperiod 1 | 592.65 | 200.21 | 52.27 | 16.62 | 69.83 | 3.145 |
| Subperiod 2 | 592.06 | 200.61 | 50.82 | 16.42 | 67.90 | 3.095 |
| First day | 1,184.71 | 400.82 | 103.09 | 33.04 | 137.73 | 3.120 |
| Subperiod 3 | 594.71 | 223.66 | 52.64 | 16.89 | 70.33 | 3.117 |
| Subperiod 4 | 595.10 | 211.99 | 51.64 | 16.66 | 68.99 | 3.100 |
| Second day | 1,189.81 | 435.65 | 104.28 | 33.55 | 139.32 | 3.108 |
| Average | 1,187.26 | 418.24 | 103.69 | 33.30 | 138.53 | 3.114 |
| Steer B, Feb. 13 and 14: |  |  |  |  |  |  |
| Subperiod 1 | 530.04 | 204.44 | 45.44 | 14.31 | 60.71 | 3.175 |
| Subperiod 2 | 543.22 | 207.09 | 45.26 | 14.83 | 60.47 | 3.052 |
| First day | 1,073.26 | 411.53 | 90.70 | 29.14 | 121.18 | 3.113 |
| Subperiod 3 | 529.31 | 205.42 | 43.96 | 14.19 | 58.74 | 3.098 |
| Subperiod 4 | 537.34 | 203.22 | 46.02 | 14.76 | 61.48 | 3.118 |
| Second day | 1,066.65 | 408.64 | 89.98 | 28.95 | 120.22 | 3.108 |
| Average | 1,069.96 | 410.09 | 90.34 | 29.05 | 120.70 | 3.110 |
| *Period II.* |  |  |  |  |  |  |
| Steer A, Mar. 6 and 7: |  |  |  |  |  |  |
| Subperiod 1 | 840.05 | 388.91 | 77.07 | 25.01 | 102.96 | 3.082 |
| Subperiod 2 | 868.33 | 403.48 | 77.62 | 25.51 | 103.70 | 3.043 |
| First day | 1,708.38 | 792.39 | 154.69 | 50.52 | 206.66 | 3.062 |
| Subperiod 3 | 862.26 | 414.33 | 74.11 | 24.26 | 99.01 | 3.055 |
| Subperiod 4 | 847.76 | 373.35 | 72.51 | 23.72 | 96.88 | 3.057 |
| Second day | 1,710.02 | 787.68 | 146.62 | 47.98 | 195.89 | 3.056 |
| Average | 1,709.20 | 790.04 | 150.66 | 49.25 | 201.28 | 3.059 |
| Steer B, Mar. 13 and 14: |  |  |  |  |  |  |
| Subperiod 1 | 657.47 | 345.12 | 58.58 | 19.00 | 78.26 | 3.083 |
| Subperiod 2 | 669.19 | 333.21 | 59.08 | 19.20 | 78.94 | 3.077 |
| First day | 1,326.66 | 678.33 | 117.66 | 38.20 | 157.20 | 3.080 |
| Subperiod 3 | 660.77 | 359.64 | 59.02 | 19.29 | 78.86 | 3.060 |
| Subperiod 4 | 684.48 | 349.57 | 58.66 | 19.01 | 78.37 | 3.086 |
| Second day | 1,345.25 | 709.21 | 117.68 | 38.30 | 157.23 | 3.073 |
| Average | 1,335.96 | 693.77 | 117.67 | 38.25 | 157.22 | 3.076 |

TABLE 172.—*Carbon and hydrogen in gaseous excreta, 1907*—Continued.

| Period. | In $CO_2$ and $H_2O$. | | In hydrocarbons. | | $CH_4$ computed from C. | H : C in hydrocarbon. |
|---|---|---|---|---|---|---|
| | Carbon. | Hydrogen. | Carbon. | Hydrogen. | | |
| *Period III.* | | | | | | |
| Steer A, Mar. 27 and 28: | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | 1 : |
| Subperiod 1 | 425.79 | 160.27 | 30.35 | 9.61 | 40.55 | 3.158 |
| Subperiod 2 | 425.52 | 157.15 | 30.52 | 9.80 | 40.78 | 3.114 |
| First day | 851.31 | 326.42 | 60.87 | 19.41 | 81.33 | 3.136 |
| Subperiod 3 | 417.80 | 159.66 | 31.62 | 9.89 | 42.25 | 3.197 |
| Subperiod 4 | 418.90 | 159.19 | 30.40 | 9.50 | 40.62 | 3.200 |
| Second day | 836.70 | 318.85 | 62.02 | 19.39 | 82.87 | 3.199 |
| Average | 844.01 | 322.64 | 61.45 | 19.40 | 82.10 | 3.168 |
| Steer B, Apr. 3 and 4: | | | | | | |
| Subperiod 1 | 422.62 | 198.60 | 29.43 | 9.21 | 39.32 | 3.195 |
| Subperiod 2 | 420.29 | 191.17 | 29.78 | 9.64 | 39.79 | 3.089 |
| First day | 842.91 | 389.77 | 59.21 | 18.85 | 79.11 | 3.141 |
| Subperiod 3 | 414.63 | 199.37 | 29.64 | 9.22 | 39.60 | 3.215 |
| Subperiod 4 | 417.03 | 190.53 | 29.68 | 9.46 | 39.66 | 3.137 |
| Second day | 831.66 | 389.90 | 59.32 | 18.68 | 79.26 | 3.176 |
| Average | 837.29 | 389.84 | 59.27 | 18.77 | 79.19 | 3.158 |
| *Period IV.* | | | | | | |
| Steer A, Apr. 17 and 18: | | | | | | |
| Subperiod 1 | 547.94 | 222.84 | 49.22 | 15.51 | 65.76 | 3.173 |
| Subperiod 2 | 554.95 | 215.46 | 48.84 | 15.76 | 65.26 | 3.099 |
| First day | 1,102.89 | 438.30 | 98.06 | 31.27 | 131.02 | 3.136 |
| Subperiod 3 | 556.31 | 229.72 | 49.31 | 15.81 | 65.88 | 3.119 |
| Subperiod 4 | 552.24 | 221.33 | 48.51 | 15.68 | 64.81 | 3.094 |
| Second day | 1,108.55 | 451.05 | 97.82 | 31.49 | 130.69 | 3.106 |
| Average | 1,105.72 | 444.68 | 97.94 | 31.38 | 130.86 | 3.121 |
| Steer B, Apr. 24 and 25: | | | | | | |
| Subperiod 1 | 533.21 | 251.08 | 46.32 | 14.84 | 61.89 | 3.121 |
| Subperiod 2 | 541.51 | 237.25 | 46.21 | 15.10 | 61.74 | 3.060 |
| First day | 1,074.72 | 488.33 | 92.53 | 29.94 | 123.63 | 3.091 |
| Subperiod 3 | 531.81 | 271.22 | 45.00 | 14.42 | 60.12 | 3.121 |
| Subperiod 4 | 538.96 | 280.41 | 46.63 | 14.94 | 62.30 | 3.121 |
| Second day | 1,070.77 | 551.63 | 91.63 | 29.36 | 122.42 | 3.121 |
| Average | 1,072.75 | 519.98 | 92.08 | 29.65 | 123.03 | 3.106 |

## THE BALANCE OF MATTER.

From the data contained in the foregoing pages the following balances have been computed in the same manner as in the previous experiments.

TABLE 173.—*The balance of matter per day and head, 1907.*

| Periods and components. | Dry matter. | Water. | | Nitrogen. | | Carbon. | | Organic hydrogen. | |
|---|---|---|---|---|---|---|---|---|---|
| | | Income. | Outgo. | Income. | Outgo. | Income. | Outgo. | Income. | Outgo. |
| *Period I.* | | | | | | | | | |
| Steer A: | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Timothy hay | 2,934.9 | 183 | | 34.8 | | 1,373.3 | | 169.5 | |
| Wheat bran | 284.7 | 327 | | 8.6 | | 130.1 | | 17.0 | |
| Corn meal | 837.1 | | | 14.4 | | 388.1 | | 52.3 | |
| Linseed meal | 874.4 | | | 50.6 | | 418.1 | | 52.9 | |
| Water | | 12,535 | | | | | | | |
| Feed residues | | | 130 | | | | | | |
| Feces | 1,546.2 | | 7,306 | | 33.1 | | 750.0 | | 87.7 |
| Urine | 446.0 | | [1]3,162 | | 72.3 | | 119.7 | | 16.4 |
| Brushings and hair | 26.2 | | 3,764 | | 1.9 | | 11.0 | | 1.4 |
| Methane | 138.5 | | | | | | 103.7 | | [2]34.6 |
| Carbon dioxid | 4,353.7 | | | | | | 1,187.3 | | |
| Water vapor | | | 3,764 | | | | | | |
| Gain or loss by body— | | | | | | | | | |
| Protein | 6.6 | | | | 1.1 | | 3.5 | | .5 |
| Fat | 175.7 | | | | | | 134.4 | | 21.1 |
| Water | | 147 | | | | | | | |
| Organic hydrogen oxidized | | 1,170 | | | | | | | 130.0 |
| | | 14,362 | 14,362 | 108.4 | 108.4 | 2,309.6 | 2,309.6 | 291.7 | 291.7 |
| Steer B: | | | | | | | | | |
| Timothy hay | 2,760.8 | 146 | | 32.8 | | 1,291.9 | | 159.4 | |
| Wheat bran | 199.7 | 226 | | 6.0 | | 91.2 | | 11.9 | |
| Corn meal | 586.0 | | | 10.0 | | 271.7 | | 36.6 | |
| Linseed meal | 612.1 | | | 35.4 | | 292.7 | | 37.0 | |
| Water | | 7,175 | | | | | | | |
| Feed residues | | | 10 | | | | | | |
| Feces | 1,410.9 | | 4,973 | | 24.5 | | 682.3 | | 81.1 |
| Urine | 399.1 | | [1]2,354 | | 58.8 | | 108.5 | | 15.0 |
| Brushings and hair | 25.6 | | | | 1.7 | | 10.5 | | 1.4 |
| Methane | 120.7 | | | | | | 90.3 | | 30.2 |
| Carbon dioxid | 3,923.6 | | | | | | 1,070.0 | | |
| Water vapor | | | 3,691 | | | | | | |
| Gain or loss by body— | | | | | | | | | |
| Protein | 4.8 | | | .8 | | 2.5 | | .3 | |
| Fat | 15.2 | | | | | 11.6 | | 1.8 | |
| Water | | 2,407 | | | | | | | |
| Organic hydrogen oxidized | | 1,074 | | | | | | | 119.3 |
| | | 11,028 | 11,028 | 85.0 | 85.0 | 1,961.6 | 1,961.6 | 247.0 | 247.0 |
| *Period II.* | | | | | | | | | |
| Steer A: | | | | | | | | | |
| Timothy hay | 2,948.7 | 223 | | 34.0 | | 1,384.7 | | 169.3 | |
| Wheat bran | 670.2 | 862 | | 20.2 | | 307.4 | | 40.2 | |
| Corn meal | 1,998.8 | | | 34.7 | | 922.3 | | 123.0 | |
| Linseed meal | 2,090.0 | | | 121.9 | | 1,009.4 | | 124.8 | |
| Water | | 17,445 | | | | | | | |
| Feed residues | | | 40 | | | | | | |
| Feces | 2,204.6 | | 11,306 | | 55.0 | | 1,049.3 | | 124.4 |
| Urine | 767.4 | | 7,158 | | 150.3 | | 189.5 | | 34.1 |
| Brushings and hair | 26.2 | | | | 1.9 | | 11.0 | | 1.4 |
| Methane | 201.3 | | | | | | 150.7 | | 50.2 |
| Carbon dioxid | 6,267.7 | | | | | | 1,709.2 | | |
| Water vapor | | | 7,110 | | | | | | |
| Gain or loss by body— | | | | | | | | | |
| Protein | 21.6 | | | | 3.6 | | 11.3 | | 1.5 |
| Fat | 657.3 | | | | | | 502.8 | | 78.9 |
| Water | | 5,587 | | | | | | | |
| Organic hydrogen oxidized | | 1,497 | | | | | | | 166.3 |
| | | 25,614 | 25,614 | 210.8 | 210.8 | 3,623.8 | 3,623.8 | 456.8 | 456.8 |

[1] In absence of daily determination of nitrogen the urine solids computed in proportion to specific gravity.
[2] Computed.

TABLE 173.—*The balance of matter per day and head, 1907*—Continued.

| Periods and components. | Dry matter. | Water. |  | Nitrogen. |  | Carbon. |  | Organic hydrogen. |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  | Income. | Outgo. | Income. | Outgo. | Income. | Outgo. | Income. | Outgo. |
| *Period II*—Contd. |  |  |  |  |  |  |  |  |  |
| Steer B: | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Timothy hay | 2,774.3 | 232 |  | 32.0 |  | 1,302.8 |  | 159.3 |  |
| Wheat bran | 377.0 |  |  | 11.4 |  | 172.9 |  | 22.6 |  |
| Corn meal | 1,124.3 | 483 |  | 19.5 |  | 518.8 |  | 69.2 |  |
| Linseed meal | 1,175.6 |  |  | 68.5 |  | 567.8 |  | 69.9 |  |
| Water |  | 12,845 |  |  |  |  |  |  |  |
| Feces | 1,542.5 |  | 5,598 |  | 32.8 |  | 737.5 |  | 84.5 |
| Urine | 510.4 |  | 2,976 |  | 87.3 |  | 143.8 |  | 22.0 |
| Brushings and hair | 25.6 |  |  |  | 1.7 |  | 10.5 |  | 1.4 |
| Methane | 157.2 |  |  |  |  |  | 117.7 |  | 39.2 |
| Carbon dioxid | 4,899.0 |  |  |  |  |  | 1,336.0 |  |  |
| Water vapor |  |  | 6,244 |  |  |  |  |  |  |
| Gain or loss by body— |  |  |  |  |  |  |  |  |  |
| Protein | 57.6 |  |  |  | 9.6 |  | 30.3 |  | 4.1 |
| Fat | 243.8 |  |  |  |  |  | 186.5 |  | 29.3 |
| Water |  |  | 6 |  |  |  |  |  |  |
| Organic hydrogen oxidized |  | 1,264 |  |  |  |  |  |  | 140.5 |
|  |  | 14,824 | 14,824 | 131.4 | 131.4 | 2,562.3 | 2,562.3 | 321.0 | 321.0 |
| *Period III.* |  |  |  |  |  |  |  |  |  |
| Steer A: |  |  |  |  |  |  |  |  |  |
| Timothy hay | 2,874.2 | 223 |  | 34.5 |  | 1,395.8 |  | 172.3 |  |
| Water |  | 8,000 |  |  |  |  |  |  |  |
| Feed residues |  |  | 23 |  |  |  |  |  |  |
| Feces | 1,112.1 |  | 3,717 |  | 17.8 |  | 551.9 |  | 65.4 |
| Urine | 447.6 |  | 3,231 |  | 32.7 |  | 78.5 |  | 12.1 |
| Brushings and hair | 26.2 |  |  |  | 1.9 |  | 11.0 |  | 1.4 |
| Methane | 82.1 |  |  |  |  |  | 61.5 |  | 20.5 |
| Carbon dioxid | 3,095.0 |  |  |  |  |  | 844.0 |  |  |
| Water vapor |  |  | 2,904 |  |  |  |  |  |  |
| Gain or loss by body— |  |  |  |  |  |  |  |  |  |
| Protein | 107.4 |  |  | 17.9 |  | 56.4 |  | 7.7 |  |
| Fat | 123.8 |  |  |  |  | 94.7 |  | 14.8 |  |
| Water |  | 793 |  |  |  |  |  |  |  |
| Organic hydrogen oxidized |  | 859 |  |  |  |  |  |  | 95.4 |
|  |  | 9,875 | 9,875 | 52.4 | 52.4 | 1,546.9 | 1,546.9 | 194.8 | 194.8 |
| Steer B: |  |  |  |  |  |  |  |  |  |
| Timothy hay | 2,798.3 | 210 |  | 32.5 |  | 1,313.2 |  | 162.1 |  |
| Water |  | 10,420 |  |  |  |  |  |  |  |
| Feces | 1,062.4 |  | 3,452 |  | 16.2 |  | 527.9 |  | 60.8 |
| Urine | 364.1 |  | 1,731 |  | 28.5 |  | 75.9 |  | 11.2 |
| Brushings and hair | 25.6 |  |  |  | 1.7 |  | 10.5 |  | 1.4 |
| Methane | 79.2 |  |  |  |  |  | 59.3 |  | 19.8 |
| Carbon dioxid | 3,070.4 |  |  |  |  |  | 837.3 |  |  |
| Water vapor |  |  | 3,509 |  |  |  |  |  |  |
| Gain or loss by body— |  |  |  |  |  |  |  |  |  |
| Protein | 83.4 |  |  | 13.9 |  | 43.8 |  | 6.0 |  |
| Fat | 201.2 |  |  |  |  | 153.9 |  | 24.1 |  |
| Water |  |  | 2,829 |  |  |  |  |  |  |
| Organic hydrogen oxidized |  | 891 |  |  |  |  |  |  | 99.0 |
|  |  | 11,521 | 11,521 | 46.4 | 46.4 | 1,510.9 | 1,510.9 | 192.2 | 192.2 |
| *Period IV.* |  |  |  |  |  |  |  |  |  |
| Steer A: |  |  |  |  |  |  |  |  |  |
| Timothy hay | 4,692.0 | 375 |  |  |  |  |  |  |  |
| Water |  | 10,585 |  | 58.5 |  | 2,303.5 |  | 284.0 |  |
| Feed residues |  |  | 83 |  |  |  |  |  |  |
| Feces | 1,876.9 |  | 8,255 |  | 29.5 |  | 931.8 |  | 108.9 |
| Urine | 506.4 |  | 4,365 |  | 28.6 |  | 108.0 |  | 14.7 |
| Brushings and hair | 26.2 |  |  |  | 1.9 |  | 11.0 |  | 1.4 |
| Methane | 130.9 |  |  |  |  |  | 97.9 |  | 32.7 |

TABLE 173.—*The balance of matter per day and head, 1907*—Continued.

| Periods and components. | Dry matter. | Water. |  | Nitrogen. |  | Carbon. |  | Organic hydrogen. |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  | Income. | Outgo. | Income. | Outgo. | Income. | Outgo. | Income. | Outgo. |
| *Period IV*—Contd. |  |  |  |  |  |  |  |  |  |
| Steer A—Continued. | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Carbon dioxid | 4,054.7 |  |  |  |  |  | 1,105.7 |  |  |
| Water vapor |  |  | 4,002 |  |  |  |  |  |  |
| Gain or loss by body— |  |  |  |  |  |  |  |  |  |
| Protein | 9.0 |  |  | 1.5 |  | 4.7 |  | .6 |  |
| Fat | 70.3 |  |  |  |  |  | 53.8 |  | 8.4 |
| Water |  | 4,678 |  |  |  |  |  |  |  |
| Organic hydrogen oxidized |  | 1,067 |  |  |  |  |  |  | 118.5 |
|  |  | 16,705 | 16,705 | 60.0 | 60.0 | 2,308.2 | 2,308.2 | 284.6 | 284.6 |
| Steer B: |  |  |  |  |  |  |  |  |  |
| Timothy hay | 4,629.8 | 337 |  | 55.4 |  | 2,180.0 |  | 268.8 |  |
| Water |  | 13,725 |  |  |  |  |  |  |  |
| Feces | 1,801.8 |  | 7,274 |  | 28.7 |  | 889.2 |  | 103.0 |
| Urine | 517.5 |  | [1] 1,939 |  | 27.4 |  | 104.7 |  | 14.5 |
| Brushings and hair | 25.6 |  |  |  | 1.7 |  | 10.5 |  | 1.4 |
| Methane | 123.0 |  |  |  |  |  | 92.1 |  | 30.7 |
| Carbon dioxid | 3,933.8 |  |  |  |  |  | 1,072.8 |  |  |
| Water vapor |  |  | 4,680 |  |  |  |  |  |  |
| Gain or loss by body— |  |  |  |  |  |  |  |  |  |
| Protein | 14.4 |  |  | 2.4 |  | 7.6 |  | 1.0 |  |
| Fat | 23.9 |  |  |  |  |  | 18.3 |  | 2.9 |
| Water |  |  | 1,225 |  |  |  |  |  |  |
| Organic hydrogen oxidized |  | 1,056 |  |  |  |  |  |  | 117.3 |
|  |  | 15,118 | 15,118 | 57.8 | 57.8 | 2,187.6 | 2,187.6 | 269.8 | 269.8 |

[1] Only 1 day; was spilled on second day.

## COMPUTED GAINS OR LOSSES OF LIVE WEIGHT.

The following tables show the computed changes of live weight in the calorimeter and the comparison of the computed and observed gain by the animals, computed in the same manner as in the experiments of 1905 and 1906:

TABLE 174.—*Computed daily gains or losses of live weight in the calorimeter, 1907.*

| Components. | Period I. |  | Period II. |  | Period III. |  | Period IV. |  |
|---|---|---|---|---|---|---|---|---|
|  | Loss. | Gain. | Loss. | Gain. | Loss. | Gain. | Loss. | Gain. |
| Steer A: | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Protein |  | 7 |  | 22 | 107 |  | 9 |  |
| Fat |  | 176 |  | 657 | 124 |  |  | 70 |
| Water | 147 |  | 5,587 |  | 793 |  | 4,678 |  |
| Correction for irregularity of excretion | 27 |  | 54 |  |  | 43 | 62 |  |
| Balance | 9 |  |  | 4,962 |  | 981 |  | 4,679 |
|  | 183 | 183 | 5,641 | 5,641 | 1,024 | 1,024 | 4,749 | 4,749 |
| Steer B: |  |  |  |  |  |  |  |  |
| Protein | 5 |  |  | 58 | 83 |  | 14 |  |
| Fat | 15 |  |  | 244 | 201 |  |  | 24 |
| Water | 2,407 |  |  | 6 |  | 2,829 |  | 1,225 |
| Correction for irregularity of excretion |  | 160 |  | 99 |  | 38 | 12 |  |
| Balance |  | 2,267 | 407 |  | 2,583 |  | 1,223 |  |
|  | 2,427 | 2,427 | 407 | 407 | 2,867 | 2,867 | 1,249 | 1,249 |

TABLE 175.—*Computed and observed gain in live weight, 1907.*

| Period. | Computed. | Observed. |
|---|---|---|
| Period I: | *Kilos.* | *Kilos.* |
| Steer A | (1) | (1) |
| Steer B | − 6.1 | − 5.4 |
| Period II: | | |
| Steer A | −13.4 | −14.0 |
| Steer B | − 1.5 | − 1.2 |
| Period III: | | |
| Steer A | − 4.6 | − 4.2 |
| Steer B | 3.6 | 4.2 |
| Period IV: | | |
| Steer A | −11.6 | −13.6 |
| Steer B | 0.9 | 0.6 |

(1) Weights not recorded.

## HEAT EMISSION AND HEAT PRODUCTION.

The following tables show the results of the determinations of the heat given off by the animals and likewise the heat production, computed by correcting for the gain or loss of matter by the body in the manner described in connection with the experiments of 1905:

TABLE 176.—*Heat emission, 1907.*

| Periods. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | By radiation. | As latent heat of water vapor. | Total. | By radiation. | As latent heat of water vapor. | Total. |
| *Period I.* | | | | | | |
| First day— | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Subperiod 1 | 3,998.1 | 1,057.7 | 5,055.8 | 3,678.4 | 1,080.1 | 4,758.5 |
| Subperiod 2 | 3,853.7 | 1,059.8 | 4,913.5 | 3,729.3 | 1,094.0 | 4,823.3 |
| Total | 7,851.8 | 2,117.5 | 9,969.3 | 7,407.7 | 2,174.1 | 9,581.8 |
| Second day— | | | | | | |
| Subperiod 3 | 4,130.2 | 1,181.6 | 5,311.8 | 3,717.6 | 1,085.3 | 4,802.9 |
| Subperiod 4 | 3,947.1 | 1,119.9 | 5,067.0 | 3,710.9 | 1,073.6 | 4,784.5 |
| Total | 8,077.3 | 2,301.5 | 10,378.8 | 7,428.5 | 2,158.9 | 9,587.4 |
| Daily average | 7,964.6 | 2,209.5 | 10,174.1 | 7,418.1 | 2,166.5 | 9,584.6 |
| *Period II.* | | | | | | |
| First day— | | | | | | |
| Subperiod 1 | 5,021.3 | 2,054.6 | 7,075.9 | 4,013.4 | 1,823.2 | 5,836.6 |
| Subperiod 2 | 5,081.9 | 2,131.6 | 7,213.5 | 3,815.3 | 1,760.4 | 5,575.7 |
| Total | 10,103.2 | 4,186.2 | 14,289.4 | 7,828.7 | 3,583.6 | 11,412.3 |
| Second day— | | | | | | |
| Subperiod 3 | 5,351.9 | 2,188.9 | 7,540.8 | 3,957.5 | 1,899.9 | 5,857.4 |
| Subperiod 4 | 4,691.4 | 1,972.4 | 6,663.8 | 3,918.4 | 1,846.8 | 5,765.2 |
| Total | 10,043.3 | 4,161.3 | 14,204.6 | 7,875.9 | 3,746.7 | 11,622.6 |
| Daily average | 10,073.3 | 4,173.8 | 14,247.0 | 7,852.3 | 3,665.2 | 11,517.5 |
| *Period III.* | | | | | | |
| First day— | | | | | | |
| Subperiod 1 | 3,145.0 | 894.3 | 4,039.3 | 2,940.2 | 1,049.2 | 3,989.4 |
| Subperiod 2 | 2,944.0 | 830.2 | 3,774.2 | 2,857.5 | 1,010.0 | 3,867.5 |
| Total | 6,089.0 | 1,724.5 | 7,813.5 | 5,797.7 | 2,059.2 | 7,856.9 |

TABLE 176.—*Heat emission, 1907*—Continued.

| Periods. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | By radiation. | As latent heat of water vapor. | Total. | By radiation. | As latent heat of water vapor. | Total. |
| *Period III*—Continued. | | | | | | |
| Second day— | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Subperiod 3 | 3,086.5 | 843.5 | 3,930.0 | 2,899.0 | 1,053.3 | 3,952.3 |
| Subperiod 4 | 2,997.6 | 841.0 | 3,838.6 | 2,866.3 | 1,006.5 | 3,872.8 |
| Total | 6,084.1 | 1,684.5 | 7,768.6 | 5,765.3 | 2,059.8 | 7,825.1 |
| Daily average | 6,086.6 | 1,704.5 | 7,791.1 | 5,781.5 | 2,059.5 | 7,841.0 |
| *Period IV.* | | | | | | |
| First day— | | | | | | |
| Subperiod 1 | 3,573.2 | 1,177.3 | 4,750.5 | 3,461.4 | 1,326.5 | 4,787.9 |
| Subperiod 2 | 3,638.3 | 1,138.3 | 4,776.6 | 3,337.7 | 1,253.3 | 4,591.0 |
| Total | 7,211.5 | 2,315.6 | 9,527.1 | 6,799.1 | 2,579.8 | 9,378.9 |
| Second day— | | | | | | |
| Subperiod 3 | 3,774.3 | 1,213.6 | 4,987.9 | 3,320.9 | 1,432.9 | 4,753.8 |
| Subperiod 4 | 3,490.9 | 1,169.3 | 4,660.2 | 3,190.9 | 1,481.4 | 4,672.3 |
| Total | 7,265.2 | 2,382.9 | 9,648.1 | 6,511.8 | 2,914.3 | 9,426.1 |
| Daily average | 7,238.3 | 2,349.3 | 9,587.6 | 6,655.4 | 2,747.1 | 9,402.5 |

TABLE 177.—*Average heat production, 1907.*

| Periods. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Heat emission. | Correction for gain by body. | Heat production. | Heat emission. | Correction for gain by body. | Heat production. |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| I | 10,174.1 | − 0.6 | 10,173.5 | 9,584.6 | −48.6 | 9,536.0 |
| II | 14,247.0 | −107.5 | 14,139.5 | 11,517.5 | 3.8 | 11,521.3 |
| III | 7,791.1 | − 18.2 | 7,772.9 | 7,841.0 | 54.0 | 7,895.0 |
| IV | 9,587.6 | − 95.0 | 9,492.6 | 9,402.5 | 25.5 | 9,428.0 |

## THE BALANCE OF ENERGY.

The energy balances, computed on the same basis as in the experiments of the previous two years, are as follows:

TABLE 178.—*The balance of energy per day and head, 1907.*

| Periods and components. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Dry matter. | Energy. | | Dry matter. | Energy. | |
| | | Income. | Outgo. | | Income. | Outgo. |
| *Period I.* | *Grams.* | *Calories.* | *Calories.* | *Grams.* | *Calories.* | *Calories.* |
| Timothy hay | 2,934.9 | 13,187.7 | .......... | 2,760.8 | 12,405.4 | .......... |
| Wheat bran | 284.7 | 1,303.6 | .......... | 199.7 | 914.4 | .......... |
| Corn meal | 837.1 | 3,796.1 | .......... | 586.0 | 2,657.4 | .......... |
| Linseed meal | 874.4 | 4,198.0 | .......... | 612.1 | 2,938.7 | .......... |
| Feces | 1,546.2 | .......... | 7,359.3 | 1,410.9 | .......... | 6,767.7 |
| Urine (corrected for nitrogen) | 446.0 | .......... | 1,216.9 | 399.1 | .......... | 1,095.1 |
| Methane | 138.5 | .......... | 1,848.2 | 120.7 | .......... | 1,610.6 |
| Metabolizable | .......... | .......... | 12,061.0 | .......... | .......... | 9,442.5 |
| Total | .......... | 22,485.4 | 22,485.4 | .......... | 18,915.9 | 18,915.9 |

TABLE 178.—*The balance of energy per day and head, 1907*—Continued.

| Periods and components. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Dry matter. | Energy. | | Dry matter. | Energy. | |
| | | Income. | Outgo. | | Income. | Outgo. |
| *Period I*—Continued. | *Grams.* | *Calories.* | *Calories.* | *Grams.* | *Calories.* | *Calories.* |
| Metabolizable | | 12,061.0 | | | 9,442.5 | |
| Heat | | | 10,173.5 | | | 9,536.0 |
| Brushings | 26.2 | | 123.0 | 25.6 | | 117.9 |
| Gain or loss by body: | | | | | | |
| Protein (corrected for nitrogen) | 6.6 | | 29.4 | 4.8 | 21.4 | |
| Fat | 175.7 | | 1,669.1 | 15.2 | 144.4 | |
| Error | | | 66.0 | | 45.6 | |
| Total | | 12,061.0 | 12,061.0 | | 9,653.9 | 9,653.9 |
| *Period II.* | | | | | | |
| Timothy hay | 2,948.7 | 13,261.8 | | 2,774.3 | 12,477.4 | |
| Wheat bran | 670.2 | 3,071.9 | | 377.0 | 1,728.0 | |
| Corn meal | 1,998.8 | 9,049.8 | | 1,124.3 | 5,090.3 | |
| Linseed meal | 2,090.0 | 10,188.1 | | 1,175.6 | 5,730.7 | |
| Feces | 2,204.6 | | 10,340.7 | 1,542.5 | | 7,371.1 |
| Urine (corrected for nitrogen) | 764.4 | | 1,991.4 | 510.4 | | 1,536.4 |
| Methane | | | 2,686.2 | 157.2 | | 2,097.8 |
| Metabolizable | | | 20,553.3 | | | 14,021.1 |
| Total | | 35,571.6 | 35,571.6 | | 25,026.4 | 25,026.4 |
| Metabolizable | | 20,553.3 | | | 14,021.1 | |
| Heat | | | 14,139.5 | | | 11,521.3 |
| Brushings | 26.2 | | 123.0 | 25.6 | | 117.9 |
| Gain or loss by body: | | | | | | |
| Protein (corrected for nitrogen) | 21.6 | | 96.3 | 57.6 | | 256.8 |
| Fat | 657.3 | | 6,244.2 | 243.8 | | 2,316.2 |
| Error | | 49.7 | | | 191.1 | |
| Total | | 20,603.0 | 20,603.0 | | 14,212.2 | 14,212.2 |
| *Period III.* | | | | | | |
| Timothy hay | 2,974.2 | 13,411.6 | | 2,798.3 | 12,618.4 | |
| Feces | 1,112.1 | | 5,475.1 | 1,062.4 | | 5,247.0 |
| Urine (corrected for nitrogen) | 447.6 | | 606.4 | 364.1 | | 627.3 |
| Methane | 82.1 | | 1,095.6 | 79.2 | | 1,056.8 |
| Metabolizable | | | 6,234.5 | | | 5,687.3 |
| Total | | 13,411.6 | 13,411.6 | | 12,618.4 | 12,618.4 |
| Metabolizable | | 6,234.5 | | | | |
| Heat | | | 7,772.9 | | 5,687.3 | 7,895.0 |
| Brushings | 26.2 | | 123.0 | 25.6 | | 117.9 |
| Loss by body: | | | | | | |
| Protein (corrected for nitrogen) | 107.4 | 478.8 | | 83.4 | 371.7 | |
| Fat | 123.8 | 1,176.0 | | 201.2 | 1,911.4 | |
| Error | | 6.6 | | | 42.5 | |
| Total | | 7,895.9 | 7,895.9 | | 8,012.9 | 8,012.9 |
| *Period IV.* | | | | | | |
| Timothy hay | 4,892.0 | 22,115.8 | | 4,629.8 | 20,930.4 | |
| Feces | 1,876.9 | | 9,236.8 | 1,801.8 | | 8,879.1 |
| Urine (corrected for nitrogen) | 506.4 | | 975.1 | 517.6 | | 964.5 |
| Methane | 130.9 | | 1,746.7 | 123.0 | | 1,641.3 |
| Metabolizable | | | 10,157.2 | | | 9,445.5 |
| Total | | 22,115.8 | 22,115.8 | | 20,930.4 | 20,930.4 |
| Metabolizable | | 10,157.2 | | | 9,445.5 | |
| Heat | | | 9,492.6 | | | 9,428.0 |
| Brushings | 26.2 | | 123.0 | 25.6 | | 117.9 |
| Gain or loss by body: | | | | | | |
| Protein (corrected for nitrogen) | 9.0 | 40.1 | | 14.4 | 64.1 | |
| Fat | 70.3 | | 667.8 | 23.9 | | 227.1 |
| Error | | 86.1 | | | 263.4 | |
| Total | | 10,283.4 | 10,283.4 | | 9,773.0 | 9,773.0 |

In general, there is an excellent agreement between the observed heat production and that computed from the carbon and nitrogen balance in the customary way, the principal exception being with Steer B in Period IV.

TABLE 179.—*Observed and computed heat production, 1907.*

| Periods. | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Observed. | Computed. | Error. | Computed +observed. | Observed. | Computed. | Error. | Computed +observed. |
| | *Calories.* | *Calories.* | *Calories.* | *Per cent.* | *Calories.* | *Calories.* | *Calories.* | *Per cent.* |
| I | 10,173.5 | 10,239.5 | +66.0 | 100.6 | 9,536.0 | 9,490.4 | − 45.6 | 99.5 |
| II | 14,139.5 | 14,089.8 | −49.7 | 99.6 | 11,521.3 | 11,330.2 | −191.1 | 98.3 |
| III | 7,772.9 | 7,766.3 | − 6.6 | 99.9 | 7,895.0 | 7,852.5 | − 42.5 | 99.5 |
| IV | 9,492.6 | 9,406.5 | −86.1 | 99.1 | 9,428.0 | 9,164.6 | −263.4 | 97.2 |

## METABOLIZABLE ENERGY.

The results for the metabolizable energy of the timothy hay and of the mixed grain are contained in the following tables, being stated in the same form as in the experiments of the two previous years.

TABLE 180.—*Percentage distribution of energy of timothy hay, 1907.*

| | Total energy. | | | Energy of digested matter. | | |
|---|---|---|---|---|---|---|
| | Period III. | Period IV. | True average. | Period III. | Period IV. | True average. |
| *Steer A.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| In feces | 40.82 | 41.77 | 41.41 | .......... | .......... | .......... |
| In urine | 4.52 | 4.40 | 4.45 | 7.64 | 7.56 | 7.60 |
| In methane | 8.17 | 7.90 | 8.00 | 13.81 | 13.57 | 13.65 |
| Metabolizable | 46.49 | 45.93 | 46.14 | 78.55 | 78.87 | 78.75 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| *Steer B.* | | | | | | |
| In feces | 41.58 | 42.42 | 42.11 | .......... | .......... | .......... |
| In urine | 4.97 | 4.61 | 4.74 | 8.51 | 8.01 | 8.19 |
| In methane | 8.38 | 7.84 | 8.04 | 14.34 | 13.61 | 13.89 |
| Metabolizable | 45.07 | 45.13 | 45.11 | 77.15 | 78.38 | 77.92 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

TABLE 181.—*Metabolizable energy per gram of organic matter of timothy hay, 1907.*

| Period. | Organic matter. | | Metabolizable energy. | | |
|---|---|---|---|---|---|
| | Total. | Digested. | Total. | Per gram total organic matter. | Per gram digested organic matter. |
| *Steer A.* | *Grams.* | *Grams.* | *Calories.* | *Calories.* | *Calories.* |
| III | 2,826.1 | 1,803.3 | 6,234.5 | 2.206 | 3.457 |
| IV | 4,641.8 | 2,917.4 | 10,157.2 | 2.188 | 3.482 |
| Totals and averages | 7,467.9 | 4,720.7 | 16,391.7 | 2.195 | 3.472 |
| *Steer B.* | | | | | |
| III | 2,659.0 | 1,683.7 | 5,687.3 | 2.139 | 3.378 |
| IV | 4,393.0 | 2,733.0 | 9,445.5 | 2.150 | 3.456 |
| Totals and averages | 7,052.0 | 4,416.7 | 15,132.8 | 1.146 | 3.426 |

TABLE 182.—*Percentage distribution of energy of mixed grains, 1907.*

| | Organic matter. | | Total energy. | Energy of excreta. | | | Metabolizable energy. |
|---|---|---|---|---|---|---|---|
| | Total. | Digestible. | | Feces. | Urine (corrected). | Methane. | |
| *Steer A.* | | | | | | | |
| Period I: | *Grams.* | *Grams.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| In total ration | 4,701.3 | 3,304.7 | 22,485.4 | 7,359.3 | 1,216.9 | 1,848.2 | 12,061.0 |
| In hay | 2,788.9 | 1,762.9 | 13,187.7 | 5,461.0 | 586.9 | 1,055.0 | 6,084.8 |
| In grain | 1,912.4 | 1,541.8 | 9,297.7 | 1,898.3 | 630.0 | 793.2 | 5,976.2 |
| Per cent of total energy | ... | ... | 100.00 | 20.42 | 6.78 | 8.52 | 64.28 |
| Per cent of digested energy | ... | ... | ... | ... | 8.52 | 10.70 | 80.78 |
| Period II: | | | | | | | |
| In total ration | 7,363.7 | 5,388.1 | 35,571.6 | 10,340.7 | 1,991.4 | 2,686.2 | 20,553.3 |
| In hay | 2,802.6 | 1,771.5 | 13,261.8 | 5,491.7 | 590.2 | 1,060.9 | 6,119.0 |
| In grain | 4,561.1 | 3,616.6 | 22,309.8 | 4,849.0 | 1,401.2 | 1,625.3 | 14,434.3 |
| Per cent of total energy | ... | ... | 100.00 | 21.73 | 6.28 | 7.29 | 64.70 |
| Per cent of digested energy | ... | ... | ... | ... | 8.02 | 9.31 | 82.67 |
| *Steer B.* | | | | | | | |
| Period I: | | | | | | | |
| In total ration | 3,962.6 | 2,687.6 | 18,915.9 | 6,767.7 | 1,095.1 | 1,610.6 | 9,442.5 |
| In hay | 2,623.5 | 1,643.1 | 12,405.4 | 5,223.9 | 588.0 | 997.4 | 5,596.1 |
| In grain | 1,339.1 | 1,044.5 | 6,510.5 | 1,543.8 | 507.1 | 613.2 | 3,846.4 |
| Per cent of total energy | ... | ... | 100.00 | 23.71 | 7.79 | 9.42 | 59.08 |
| Per cent of digested energy | ... | ... | ... | ... | 10.21 | 12.35 | 77.44 |
| Period II: | | | | | | | |
| In total ration | 5,202.3 | 3,814.2 | 25,026.4 | 7,371.1 | 1,536.4 | 2,097.8 | 14,021.1 |
| In hay | 2,636.8 | 1,651.4 | 12,477.4 | 5,254.2 | 591.4 | 1,003.2 | 5,628.6 |
| In grain | 2,565.5 | 2,162.8 | 12,549.0 | 2,116.9 | 945.0 | 1,094.6 | 8,392.5 |
| Per cent of total energy | ... | ... | 100.00 | 16.87 | 7.53 | 8.72 | 66.88 |
| Per cent of digested energy | ... | ... | ... | ... | 9.06 | 10.48 | 80.46 |

TABLE 183.—*Metabolizable energy per gram organic matter of mixed grain, 1907.*

| Periods. | Organic matter. | | Metabolizable energy. | | |
|---|---|---|---|---|---|
| | Total. | Digested. | Total. | Per gram total organic matter. | Per gram digested organic matter. |
| *Steer A.* | *Grams.* | *Grams.* | *Calories.* | *Calories.* | *Calories.* |
| I | 1,912.4 | 1,541.8 | 5,976.2 | 3.125 | 3.876 |
| II | 4,561.1 | 3,616.6 | 14,434.3 | 3.165 | 3.991 |
| Average | ... | ... | ... | 3.145 | ... |
| *Steer B.* | | | | | |
| I | 1,339.1 | 1,044.5 | 3,846.4 | 2.872 | 3.683 |
| II | 2,565.5 | 2,162.8 | 8,392.5 | 3.271 | 3.880 |
| Average | ... | ... | ... | 3.072 | ... |

## CORRECTION OF HEAT PRODUCTION FOR STANDING AND LYING.

The following tables afford the data necessary for correcting the observed heat production for variations in the proportion of time spent standing and lying:

TABLE 184.—*Heat emitted by radiation and conduction during periods of standing and lying, 1907.*

| Periods. | Standing. | | Lying. | |
|---|---|---|---|---|
| | Elapsed time. | Total heat. | Elapsed time. | Total heat. |
| *Period I.* | | | | |
| Steer A: | *Minutes.* | *Calories.* | *Minutes.* | *Calories.* |
| 6.00 p. m. to 7.00 p. m. | 60 | 314.14 | | |
| 7.20 p. m. to 9.08 p. m. | 108 | 637.21 | | |
| 9.48 p. m. to 12.40 a. m. | | | 172 | 841.88 |
| 1.00 a. m. to 1.20 a. m. | 20 | 125.72 | | |
| 1.40 a. m. to 2.12 a. m. | 32 | 212.22 | | |
| 3.24 a. m. to 4.12 a. m. | | | 48 | 230.09 |
| 4.36 a. m. to 6.00 a. m. | 84 | 517.60 | | |
| 6.00 a. m. to 7.40 a. m. | 100 | 573.14 | | |
| 8.04 a. m. to 8.56 a. m. | | | 52 | 229.91 |
| 9.16 a. m. to 9.40 a. m. | 24 | 151.41 | | |
| 10.00 a. m. to 12.04 p. m. | | | 124 | 564.44 |
| 12.24 p. m. to 12.56 p. m. | 32 | 211.85 | | |
| 1.24 p. m. to 2.44 p. m. | | | 80 | 350.30 |
| 3.04 p. m. to 3.44 p. m. | 40 | 259.28 | | |
| 4.08 p. m. to 4.20 p. m. | | | 12 | 54.49 |
| 4.40 p m. to 6.00 p. m. | 80 | 483.20 | | |
| 6.00 p. m to 8.24 p. m. | 144 | 887.25 | | |
| 8.52 p. m. to 9.16 p. m. | 24 | 156.98 | | |
| 9.40 p. m. to 10.32 p. m. | | | 52 | 261.76 |
| 11.20 p. m. to 1.16 a. m. | | | 116 | 600.74 |
| 1.56 a. m. to 4.08 a. m. | | | 132 | 676.36 |
| 4.28 a. m. to 6.00 a. m. | 92 | 582.27 | | |
| 6.00 a. m. to 7.52 a. m. | 112 | 661.39 | | |
| 8.16 a. m. to 9.56 a. m. | | | 100 | 441.28 |
| 10.16 a. m. to 10.52 a. m. | 36 | 239.38 | | |
| 11.16 a. m. to 12.36 p. m. | | | 80 | 372.09 |
| 12.56 p. m. to 1.20 p. m. | 24 | 159.08 | | |
| 1.44 p. m. to 3.32 p. m. | | | 108 | 503.16 |
| 3.52 p. m. to 6.00 p. m. | 128 | 795.35 | | |
| Totals | 1,140 | 6,967.47 | 1,076 | 5,126.50 |
| Corrections for capacity, feed, water, excreta, etc | | +63.97 | | −72.33 |
| | | 7,031.44 | | 5,054.17 |
| Heat per minute | | 6.1679 | | 4.6972 |
| Steer B: | | | | |
| 6.20 p. m. to 7.20 p. m. | 60 | 333.30 | | |
| 7.56 p. m. to 12.08 a. m. | | | 252 | 1,139.94 |
| 12.44 a. m. to 2.04 a. m. | 80 | 525.91 | | |
| 2.28 a. m. to 4.40 a. m. | | | 132 | 589.50 |
| 5.08 a. m. to 6.00 a. m. | 52 | 317.07 | | |
| 6.00 a. m. to 7.56 a. m. | 116 | 664.87 | | |
| 8.20 a m. to 10.24 a. m. | | | 124 | 467.31 |
| 10.44 a. m. to 11.105 a. m | 26.5 | 171.75 | | |
| 11.15 a. m. to 12.28 p. m. | 77.5 | 496.54 | | |
| 12.52 p. m. to 2.20 p. m. | | | 88 | 346.51 |
| 2.40 p. m. to 6.00 p. m. | 200 | 1,131.33 | | |
| 6.00 p. m. to 8.08 p. m. | 128 | 757.06 | | |
| 8.32 p. m. to 10.12 p. m. | | | 100 | 441.98 |
| 10.32 p. m. to 12.24 a. m. | 112 | 715.39 | | |
| 12.48 a. m. to 5.24 a. m. | | | 276 | 1,221.74 |
| 5.44 a. m. to 6.00 a. m. | 16 | 99.93 | | |
| 6.00 a. m. to 9.04 a. m. | 184 | 1,069.85 | | |
| 9.28 a. m. to 12.56 p. m. | | | 208 | 869.01 |
| 1.20 p. m. to 3.08 p. m. | | | 108 | 481.86 |
| 3.28 p. m. to 3.58 p. m. | 30 | 178.22 | | |
| 3.58 p. m. to 4.385 p. m | 40.5 | 248.98 | | |
| 4.38 p. m. to 6.00 p. m. | 81.5 | 486.07 | | |
| Totals | 1,204 | 7,196.27 | 1,288 | 5,557.85 |
| Corrections for capacity, feed, water, excreta, etc | | +8.77 | | −41.42 |
| | | 7,205.04 | | 5,516.43 |
| Heat per minute | | 5.9843 | | 4.2829 |

TABLE 184.—*Heat emitted by radiation and conduction during periods of standing and lying, 1907*—Continued.

| Periods. | Standing. | | Lying. | |
|---|---|---|---|---|
| | Elapsed time. | Total heat. | Elapsed time. | Total heat. |
| *Period II.* | | | | |
| Steer A: | *Minutes.* | *Calories.* | *Minutes.* | *Calories.* |
| 6.00 p. m. to 7.16 p. m. | 76 | 536.73 | | |
| 7.40 p. m. to 8.04 p. m. | | | 24 | 135.95 |
| 9.24 p. m. to 11.00 p. m. | 96 | 853.67 | | |
| 12.12 a. m. to 1.24 a. m. | 72 | 598.91 | | |
| 1.48 a. m. to 4.40 a. m. | | | 172 | 916.21 |
| 5.12 a. m. to 6.00 a. m. | 48 | 374.87 | | |
| 6.00 a. m. to 6.225 a. m. | 22.5 | 175.31 | | |
| 6.22 a. m. to 7.20 a. m. | 57.5 | 433.01 | | |
| 7.40 a. m. to 8.03 a. m. | | | 23 | 128.35 |
| 8.03 a. m. to 8.32 a. m. | | | 29 | 149.60 |
| 9.28 a. m. to 10.08 a. m. | | | 40 | 211.64 |
| 11.40 a. m. to 12.28 p. m. | | | 48 | 300.34 |
| 12.48 p. m. to 1.12 p. m. | 24 | 209.71 | | |
| 1.28 p. m. to 2.28 p. m. | | | 60 | 340.32 |
| 2.48 p. m. to 3.16 p. m. | 28 | 238.24 | | |
| 3.44 p. m. to 6.00 p. m. | 136 | 1,014.72 | | |
| 6.00 p. m. to 10.48 p. m. | 288 | 2,273.52 | | |
| 11.08 p. m. to 11.24 p. m. | | | 16 | 91.08 |
| 11.48 p. m. to 12.28 a. m. | 40 | 328.69 | | |
| 12.44 a. m. to 1.44 a. m. | 60 | 470.31 | | |
| 4.40 a. m. to 6.00 a. m. | 80 | 526.81 | | |
| 6.00 a. m. to 7.285 a. m. | 88.5 | 606.22 | | |
| 7.285 a. m. to 8.08 a. m. | 39.5 | 263.62 | | |
| 8.40 a. m. to 9.30 a. m. | | | 50 | 264.66 |
| 9.30 a. m. to 10.12 a. m. | | | 42 | 202.09 |
| 10.32 a. m. to 11.08 a. m. | 36 | 291.42 | | |
| 11.32 a. m. to 12.16 p. m. | | | 44 | 226.28 |
| 12.40 p. m. to 3.12 p. m. | 152 | 1,191.70 | | |
| 3.32 p. m. to 5.00 p. m. | | | 88 | 404.92 |
| 5.20 p. m. to 6.00 p. m. | 40 | 301.63 | | |
| Totals | 1,384 | 10,689.09 | 636 | 3,371.44 |
| Corrections for capacity, feed, water, excreta, etc | | +104.54 | | −31.93 |
| | | 10,793.63 | | 3,339.51 |
| Heat per minute | | 7.7989 | | 5.2508 |
| Steer B: | | | | |
| 6.00 p. m. to 7.24 p. m. | 84 | 569.87 | | |
| 8.16 p. m. to 8.40 p. m. | 24 | 168.39 | | |
| 9.00 p. m. to 9.217 p. m. | | | 21.7 | 99.83 |
| 9.217 p. m. to 9.56 p. m. | | | 34.3 | 140.09 |
| 10.16 p. m. to 11.00 p. m. | 44 | 305.23 | | |
| 11.24 p. m. to 12.12 a. m. | | | 48 | 201.80 |
| 12.32 a. m. to 12.56 a. m. | 24 | 177.55 | | |
| 1.40 a. m. to 2.36 a. m. | | | 56 | 255.47 |
| 2.56 a. m. to 3.12 a. m. | 16 | 115.34 | | |
| 3.36 a. m. to 4.44 a. m. | | | 68 | 307.07 |
| 5.04 a. m. to 6.00 a. m. | 56 | 443.03 | | |
| 6.00 a. m. to 7.32 a. m. | 92 | 552.49 | | |
| 7.56 a. m. to 9.16 a. m. | | | 80 | 323.00 |
| 9.36 a. m. to 10.52 a. m. | 76 | 541.00 | | |
| 11.44 a. m. to 12.44 p. m. | | | 60 | 243.13 |
| 1.04 p. m. to 1.20 p. m. | 16 | 115.71 | | |
| 1.44 p. m. to 3.04 p. m. | | | 80 | 349.65 |
| 3.56 p. m. to 5.08 p. m. | | | 72 | 277.72 |
| 5.28 p. m. to 6.00 p. m. | 32 | 222.73 | | |
| 6.00 p. m. to 7.20 p. m. | 80 | 529.05 | | |
| 7.44 p. m. to 8.36 p. m. | | | 52 | 220.61 |
| 8.56 p. m. to 9.04 p. m. | | | 8 | 41.77 |
| 9.24 p. m. to 9.40 p. m. | | | 16 | 88.05 |
| 10.00 p. m. to 11.44 p. m. | 104 | 718.15 | | |
| 12.32 a. m. to 1.04 a. m. | | | 32 | 127.65 |
| 1.28 a. m. to 4.20 a. m. | | | 172 | 790.97 |
| 4.40 a. m. to 6.00 a. m. | 80 | 530.58 | | |
| 6.00 a. m. to 6.34 a. m. | 34 | 216.99 | | |
| 6.34 a. m. to 8.08 a. m. | 94 | 548.19 | | |
| 8.32 a. m. to 11.56 a. m. | | | 204 | 888.34 |
| 12.16 p. m. to 1.52 p. m. | 96 | 679.84 | | |
| 2.16 p. m. to 4.00 p. m. | | | 104 | 459.45 |
| 4.20 p. m. to 6.00 p. m. | 100 | 625.25 | | |
| Totals | 1,052 | 7,059.39 | 1,108 | 4,814.60 |
| Corrections for capacity, water, feed, excreta, etc | | −103.57 | | +66.30 |
| | | 6,955.82 | | 4,880.90 |
| Heat per minute | | 6.6120 | | 4.4051 |

TABLE 184.—*Heat emitted by radiation and conduction during periods of standing and lying, 1907*—Continued.

| Periods. | Standing. | | Lying. | |
|---|---|---|---|---|
| | Elapsed time. | Total heat. | Elapsed time. | Total heat. |
| *Period III.* | | | | |
| Steer A: | *Minutes.* | *Calories.* | *Minutes.* | *Calories.* |
| 6.00 p. m. to 7.02 p. m. | 62 | 256.20 | | |
| 7.02 p. m. to 7.505 p. m. | 48.5 | 212.71 | | |
| 7.505 p. m. to 8.02 p. m. | 12.2 | 53.75 | | |
| 8.02 p. m. to 8.075 p. m. | 4.8 | 22.37 | | |
| 8.075 p. m. to 8.505 p. m. | 43.0 | 206.33 | | |
| 8.505 p. m. to 11.24 p. m. | 153.5 | 792.00 | | |
| 11.48 p. m. to 12.14 a. m. | | | 26 | 93.07 |
| 12.14 a. m. to 3.56 a. m. | | | 222 | 821.08 |
| 4.16 a. m. to 6.00 a. m. | 104 | 531.62 | | |
| 6.00 a. m. to 8.32 a. m | 152 | 706.34 | | |
| 8.56 a. m. to 12.12 p. m. | | | 196 | 648.45 |
| 1.24 p. m. to 3.00 p. m. | | | 96 | 366.00 |
| 3.20 p. m. to 6.00 p. m. | 160 | 770.27 | | |
| 6.00 p. m. to 7.36 p. m. | 96 | 459.20 | | |
| 8.00 p. m. to 11.00 p. m. | | | 180 | 650.60 |
| 11.20 p. m. to 11.40 p. m. | 20 | 109.79 | | |
| 12.04 a. m. to 1.04 a. m. | | | 60 | 241.57 |
| 1.24 a. m. to 1.48 a. m. | 24 | 137.05 | | |
| 2.12 a. m. to 4.44 a. m. | | | 152 | 569.40 |
| 5.04 a. m. to 6.00 a. m. | 56 | 292.54 | | |
| 6.00 a. m. to 7.36 a. m. | 96 | 454.25 | | |
| 8.40 a. m. to 10.12 a. m. | | | 92 | 308.70 |
| 10.32 a. m. to 11.04 a. m. | 32 | 162.56 | | |
| 11.28 a. m. to 1.08 p. m. | | | 100 | 368.39 |
| 1.28 p. m. to 1.56 p. m. | 28 | 139.00 | | |
| 2.20 p. m. to 4.04 p. m. | | | 104 | 374.88 |
| 4.24 p. m. to 5.07 p. m. | 43 | 215.00 | | |
| 5.07 p. m. to 6.00 p. m. | 53 | 269.77 | | |
| Totals | 1,188 | 5,790.75 | 1,228 | 4,442.14 |
| Corrections for capacity, water, feed, excreta, etc. | | −47.9 | | −33.64 |
| | | 5,742.85 | | 4,408.50 |
| Heat per minute | | 4.8340 | | 3.5900 |
| Steer B: | | | | |
| 6.00 p. m. to 8.08 p. m. | 128 | 602.47 | | |
| 8.32 p. m. to 10.12 p. m. | | | 100 | 331.24 |
| 10.32 p. m. to 11.24 p. m. | 52 | 279.14 | | |
| 11.52 p. m. to 3.12 a. m. | | | 200 | 729.79 |
| 3.32 a. m. to 4.16 a. m. | 44 | 227.16 | | |
| 4.40 a. m. to 5.40 a. m. | | | 60 | 209.76 |
| 6.00 a. m. to 8.44 a. m. | 164 | 742.63 | | |
| 9.08 a. m. to 11.56 a. m. | | | 168 | 506.33 |
| 1.24 p. m. to 4.04 p. m. | | | 160 | 571.79 |
| 4.24 p. m. to 6.00 p. m. | 96 | 474.01 | | |
| 6.00 p. m. to 7.12 p. m. | 72 | 327.70 | | |
| 7.36 p. m. to 10.32 p. m. | | | 176 | 634.84 |
| 11.28 p. m. to 1.40 a. m. | | | 132 | 491.45 |
| 2.16 a. m. to 4.00 a. m. | | | 104 | 404.38 |
| 4.12 a. m. to 4.30 a. m. | 18 | 89.43 | | |
| 5.20 a. m. to 5.265 a. m. | 6.5 | 35.44 | | |
| 5.265 a. m. to 6.00 a. m. | 33.5 | 176.50 | | |
| 6.00 a. m. to 7.40 a. m. | 100 | 476.87 | | |
| 8.04 a. m. to 10.12 a. m. | | | 128 | 426.33 |
| 10.32 a. m. to 10.52 a. m. | 20 | 100.96 | | |
| 11.16 a. m. to 1.08 p. m. | | | 112 | 384.03 |
| 1.28 p. m. to 1.48 p. m. | 20 | 100.05 | | |
| 2.12 p. m. to 3.40 p. m. | | | 88 | 299.31 |
| 4.00 p. m. to 4.245 p. m. | 24.5 | 124.27 | | |
| 4.245 p. m. to 4.40 p. m. | 15.5 | 77.87 | | |
| 5.04 p. m. to 5.20 p. m. | | | 16 | 52.14 |
| 5.40 p. m. to 6.00 p. m. | 20 | 98.31 | | |
| Totals | 814 | 3,932.80 | 1,444 | 5,041.39 |
| Corrections for capacity, water, feed, excreta, etc. | | −93.03 | | −53.94 |
| | | 3,839.77 | | 4,987.45 |
| Heat per minute | | 4.7172 | | 3.4539 |

TABLE 184.—*Heat emitted by radiation and conduction during periods of standing and lying, 1907*—Continued.

| Periods. | Standing. | | Lying. | |
|---|---|---|---|---|
| | Elapsed time. | Total heat. | Elapsed time. | Total heat. |
| *Period IV.* | | | | |
| Steer A: | *Minutes.* | *Calories.* | *Minutes.* | *Calories.* |
| 6.00 p. m. to 7.36 p. m. | 96 | 526.62 | | |
| 8.28 p. m. to 10.28 p. m. | 120 | 711.38 | | |
| 10.52 p. m. to 2.08 a. m. | | | 196 | 818.42 |
| 2.48 a. m. to 4.36 a. m. | | | 108 | 475.47 |
| 4.56 a. m. to 6.00 a. m. | 64 | 377.00 | | |
| 6.00 a. m. to 7.44 a. m. | 104 | 582.10 | | |
| 8.08 a. m. to 8.28 a. m. | | | 20 | 80.83 |
| 8.48 a. m. to 9.16 a. m. | 28 | 160.18 | | |
| 9.40 a. m. to 10.24 a. m. | | | 44 | 175.66 |
| 10.44 a. m. to 12.32 p. m. | 108 | 631.48 | | |
| 12.56 p. m. to 3.20 p. m. | | | 144 | 571.97 |
| 3.40 p. m. to 6.00 p. m. | 140 | 785.35 | | |
| 6.00 p. m. to 7.48 p. m. | 108 | 607.77 | | |
| 8.12 p. m. to 8.52 p. m. | | | 40 | 185.18 |
| 9.12 p. m. to 9.52 p. m. | 40 | 254.71 | | |
| 10.16 p. m. to 11.40 p. m. | | | 84 | 392.41 |
| 12.00 a. m. to 1.04 a. m. | 64 | 407.00 | | |
| 1.28 a. m. to 3.56 a. m. | | | 148 | 632.39 |
| 4.16 a. m. to 4.575 a. m. | 41.5 | 253.22 | | |
| 4.575 a. m. to 6.00 a. m. | 62.5 | 361.57 | | |
| 6.00 a. m. to 7.12 a. m. | 72 | 403.18 | | |
| 7.36 a. m. to 8.28 a. m. | | | 52 | 211.28 |
| 9.16 a. m. to 9.36 a. m. | | | 20 | 91.52 |
| 9.56 a. m. to 10.12 a. m. | 16 | 99.89 | | |
| 10.40 a. m. to 1.48 p. m. | | | 188 | 802.50 |
| 2.36 p. m. to 4.04 p. m. | | | 88 | 386.57 |
| 4.24 p. m. to 6.00 p. m. | 96 | 563.71 | | |
| Totals | 1,160 | 6 725.10 | 1,132 | 4,824.20 |
| Corrections for capacity, water, feed, excreta, etc | | −5.94 | | −45.09 |
| | | 6,719.16 | | 4,779.11 |
| Heat per minute | | 5.7924 | | 4.2218 |
| Steer B: | | | | |
| 6.00 p. m. to 6.48 p. m. | 48 | 266.10 | | |
| 7.12 p. m. to 8.00 p. m. | | | 48 | 188.52 |
| 8.20 p. m. to 8.52 p. m. | 32 | 191.30 | | |
| 9.16 p. m. to 10.44 p. m. | | | 88 | 376.85 |
| 11.04 p. m. to 11.36 p. m. | 32 | 199.52 | | |
| 12.04 a. m. to 12.44 a. m. | | | 40 | 160.31 |
| 1.04 a. m. to 1.28 a. m. | 24 | 148.10 | | |
| 2.00 a. m. to 4.28 a. m. | | | 148 | 600.22 |
| 4.48 a. m. to 6.00 a. m. | 72 | 417.37 | | |
| 6.00 a. m. to 7.28 a. m. | 88 | 471.32 | | |
| 7.28 a. m. to 8.56 a. m. | | | 64 | 226.09 |
| 9.16 a. m. to 10.16 a. m. | 60 | 334.36 | | |
| 10.44 a. m. to 11.28 a. m. | | | 44 | 159.96 |
| 11.48 a. m. to 12.36 p. m. | 48 | 281.00 | | |
| 1.00 p. m. to 3.04 p. m. | | | 124 | 490.71 |
| 3.34 p. m. to 4.12 p. m. | 48 | 285.75 | | |
| 4.36 p. m. to 5.36 p. m. | | | 60 | 233.27 |
| 6.00 p. m. to 7.16 p. m. | 76 | 417.20 | | |
| 7.40 p. m. to 8.36 p. m. | | | 56 | 223.26 |
| 8.56 p. m. to 9.28 p. m. | 32 | 196.24 | | |
| 9.52 p. m. to 11.12 p. m. | | | 80 | 323.61 |
| 11.32 p. m. to 12.24 a. m. | 52 | 308.21 | | |
| 12.48 a. m. to 4.20 a. m. | | | 212 | 838.73 |
| 6.00 a. m. to 7.08 a. m. | 68 | 364.17 | | |
| 7.32 a. m. to 10.04 a. m. | | | 152 | 540.32 |
| 10.24 a. m. to 11.24 a. m. | 60 | 330.47 | | |
| 11.48 a. m. to 12.12 p. m. | | | 24 | 101.75 |
| 12.32 p. m. to 12.56 p. m. | 24 | 135.79 | | |
| 1.20 p. m. to 2.16 p. m. | | | 56 | 216.19 |
| 2.40 p. m. to 4.04 p. m. | | | 84 | 313.92 |
| 4.24 p. m. to 6.00 p. m. | 96 | 486.89 | | |
| Totals | 800 | 4,833.79 | 1,280 | 4,993.72 |
| Corrections for capacity, water, feed, excreta, etc | | −7.08 | | −86.64 |
| | | 4,826.71 | | 4,907.08 |
| Heat per minute | | 5.6125 | | 3.8337 |

TABLE 185.—*Average heat per minute emitted by radiation and conduction, 1907.*

| Periods. | Standing. | Lying. |
|---|---|---|
| *Steer A.* | *Calories.* | *Calories.* |
| I | 6.1679 | 4.0972 |
| II | 7.7989 | 5.2506 |
| III | 4.8340 | 3.5900 |
| IV | 5.7924 | 4.2218 |
| *Steer B.* | | |
| I | 5.9843 | 4.2829 |
| II | 6.6120 | 4.4051 |
| III | 4.7172 | 3.4539 |
| IV | 5.6125 | 3.8337 |

The following table shows the total heat emission and production corrected to 12 hours standing, as in the previous experiments.

TABLE 186.—*Heat production corrected to 12 hours standing, 1907.*

| Periods. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Total heat emission. | Correction for gain of matter by body. | Total heat production. | Total heat emission. | Correction for gain of matter by body. | Total heat production. |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| I | 10,164.3 | − 0.6 | 10,163.7 | 9,648.8 | −48.6 | 9,600.2 |
| II | 13,482.7 | −107.5 | 13,375.2 | 11,716.0 | + 3.8 | 11,719.8 |
| III | 7,809.1 | − 18.2 | 7,790.9 | 8,009.9 | +54.0 | 8,063.9 |
| IV | 9,618.4 | − 95.0 | 9,523.4 | 9,786.0 | +25.5 | 9,811.5 |

## AVAILABILITY OF METABOLIZABLE ENERGY.

The following tables show the gain of energy by the animals, as computed from the corrected heat production of Table 186, and the average live weights of the animals for the last six days of each period.

TABLE 187.—*Corrected gains of energy by the animals, 1907.*

| | Steer A. | | Steer B. | |
|---|---|---|---|---|
| | Income. | Outgo. | Income. | Outgo. |
| Period I: | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Metabolizable | 12,061.0 | | 9,442.5 | |
| Brushings | | 123.0 | | 117.9 |
| Heat (from Table 186) | | 10,163.7 | | 9,600.2 |
| Gain | | 1,774.3 | 275.6 | |
| | 12,061.0 | 12,061.0 | 9,718.1 | 9,718.1 |
| Period II: | | | | |
| Metabolizable | 20,553.3 | | 14,021.1 | |
| Brushings | | 123.0 | | 117.9 |
| Heat (from Table 186) | | 13,375.2 | | 11,719.8 |
| Gain | | 7,055.1 | | 2,183.4 |
| | 20,553.3 | 20,553.3 | 14,021.1 | 14,021.1 |
| Period III: | | | | |
| Metabolizable | 6,234.5 | | 5,687.3 | |
| Brushings | | 123.0 | | 117.9 |
| Heat (from Table 186) | | 7,790.9 | | 8,063.9 |
| Gain | 1,679.4 | | 2,494.5 | |
| | 7,913.9 | 7,913.9 | 8,181.8 | 8,181.8 |
| Period IV: | | | | |
| Metabolizable | 10,157.2 | | 9,445.5 | |
| Brushings | | 123.0 | | 117.9 |
| Heat (from Table 186) | | 9,523.4 | | 9,811.5 |
| Gain | | 510.8 | 483.9 | |
| | 10,157.2 | 10,157.2 | 9,929.4 | 9,929.4 |

TABLE 188.—*Average live weights for last six days of each period, 1907.*

| Periods. | Steer A. | Steer B. |
|---|---|---|
| | *Kilos.* | *Kilos.* |
| I | 498.6 | 372.6 |
| II | 518.7 | 386.4 |
| III | 507.3 | 373.7 |
| IV | 514.2 | 384.9 |

TIMOTHY HAY.

A comparison of Periods III and IV in the same manner as in previous experiments gives the following results for the availability of the metabolizable energy of the timothy hay:

TABLE 189.—*Availability of metabolizable energy of timothy hay, 1907.*

| Steer A—Periods IV-III. | Steer B—Periods IV-III. |
|---|---|
| $n=\left(\frac{507.3}{514.2}\right)^{2/3}=0.9910.$ | $n=\left(\frac{373.7}{384.9}\right)^{2/3}=0.9806$ |
| $x_3=6{,}234.5 \quad y_3=-1{,}679.4$ | $x_3=5{,}687.3 \quad y_3=-2{,}494.5$ |
| $x_4=10{,}157.2 \quad y_4=510.8$ | $x_4=9{,}445.5 \quad y_4=-483.9$ |
| $m=\frac{-1{,}679.4-(0.991\times510.8)}{6{,}234.5-(0.991\times10{,}157.2)}=57.05$ per cent. | $m=\frac{-2{,}494.5-(0.9806\times-483.9)}{5{,}687.3-(0.9806\times9{,}445.5)}=56.50$ per cent. |

MIXED GRAIN.

Correcting the results of Periods I and II for the differences in the amounts of hay consumed as compared with the basal ration of Period III, the availability of the metabolizable energy of the mixed grain may be computed as follows:

TABLE 190.—*Correction for differences in amounts of hay eaten, 1907.*

| Periods. | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Organic matter of hay. | Metabolizable energy of total ration. | Gain by animal. | Organic matter of hay. | Metabolizable energy of total ration. | Gain by animal. |
| | *Grams.* | *Calories.* | *Calories.* | *Grams.* | *Calories.* | *Calories.* |
| Period III | 2,826.1 | | | 2,659.0 | | |
| Period I | 2,788.9 | 12,061.0 | 1,774.3 | 2,623.5 | 9,442.5 | −275.6 |
| Correction | 37.2 | 81.7 | 46.6 | 35.5 | 76.2 | 43.1 |
| Period I, corrected | 2,826.1 | 12,142.7 | 1,820.9 | 2,659.0 | 9,518.7 | −232.5 |
| Period III | 2,826.1 | | | 2,659.0 | | |
| Period II | 2,802.6 | 20,553.3 | 7,055.1 | 2,636.8 | 14,021.1 | 2,183.4 |
| Correction | 23.5 | 51.6 | 29.4 | 22.2 | 47.6 | 26.9 |
| Period II, corrected | 2,826.1 | 20,604.9 | 7,084.5 | 2,659.0 | 14,068.7 | 2,210.3 |

TABLE 191.—*Availability of metabolizable energy of mixed grain.*

| Steer A—Periods I-III. | Steer B—Periods I-III. |
|---|---|
| $n=\left(\frac{507.3}{498.6}\right)^{2/3}=1.012$<br>$x_3=6,234.5$ $y_3=-1,679.4$<br>$x_1=12,142.7$ $y_1=\ 1,820.9$<br>$m=\frac{-1,679.4-(1.012\times\ 1,820.9)}{6,234.5-(1.012\times 12,142.7)}=58.18$ per cent. | $n=\left(\frac{373.7}{372.6}\right)^{2/3}=1.002$<br>$x_3=5,687.3$ $y_3=-2,494.5$<br>$x_1=9,518.7$ $y_1=-232.5$<br>$m=\frac{-6,494.5-(1.002\times -232.5)}{5,687.3-(1.002\times 9,518.7)}=58.73$ per cent. |
| **Steer A—Periods II-III.** | **Steer B—Periods II-III.** |
| $n=\left(\frac{507.3}{518.7}\right)^{2/3}=0.9854$<br>$x_3=6,234.5$ $y_3=-1,679.4$<br>$x_2=20,604.9$ $y_2=7,084.5$<br>$m=\frac{-1,679.4-(0.9854\times\ 7,084.5)}{6,234.5-(0.9854\times 20,604.9)}=61.55$ per cent. | $n=\left(\frac{373.7}{386.4}\right)^{2/3}=0.9777$<br>$x_3=5,687.3$ $y_3=-2,494.5$<br>$x_2=14,068.7$ $y_2=2,210.3$<br>$m=\frac{-2,494.5-(0.9777\times\ 2,210.3)}{5,687.3-(0.9777\times 14,068.7)}=57.71$ per cent. |
| **Steer A—Periods II-I.** | **Steer B—Periods II-I.** |
| $n=\left(\frac{498.6}{518.7}\right)^{2/3}=0.9738$<br>$x_1=12,142.7$ $y_1=1,820.9$<br>$x_2=20,604.9$ $y_2=7,084.5$<br>$m=\frac{1,820.9-(0.9738\times\ 7,084.5)}{12,142.7-(0.9738\times 20,604.9)}=64.10$ per cent. | $n=\left(\frac{372.6}{386.4}\right)^{2/3}=0.9757$<br>$x_1=\ 9,518.7$ $y_1=-232.5$<br>$x_2=14,068.7$ $y_2=2,210.3$<br>$m=\frac{-232.5-(0.9757\times\ 2,210.3)}{9,518.7-(0.9757\times 14,068.7)}=56.74$ per cent. |

The results are summarized in the following table and represented graphically in figure 9:

TABLE 192.—*Summary of percentage availability of metabolizable energy.*

| Feed. | Steer A. | Steer B. |
|---|---|---|
| Timothy hay | 57.05 | 56.50 |
| Mixed grain: | | |
| Periods I-III | 58.18 | 58.73 |
| Periods II-I | 64.10 | 56.74 |
| Periods II-III | 61.55 | 57.71 |

## RECALCULATION OF RESPIRATION CALORIMETER EXPERIMENTS OF 1903.

As noted in Part I of the present bulletin, the results regarding availability reported in Bulletin 74 of this Bureau were computed without the correction to a uniform time of standing and lying which has been applied to the later experiments. The difference in this respect is sufficient to materially alter the teaching of the experiments, hence a recalculation of the results as published in Bulletin 74 has been made, which is tabulated below.

As a basis for the computation, the heat emission per day, as formerly reported, is retabulated so as to show the percentage of heat given off as latent heat of water vapor.

TABLE 193.—*Heat emission per day, 1903.*

| Periods. | Radiation and conduction. | In water vapor. | Total. | Per cent in water vapor. |
|---|---|---|---|---|
| | *Calories.* | *Calories.* | *Calories.* | *Per cent.* |
| I | 8,933.43 | 2,721.95 | 11,655.38 | 23.35 |
| II | 7,477.55 | 2,608.97 | 10,086.52 | 25.87 |
| III | 7,723.05 | 2,807.33 | 10,530.38 | 26.66 |
| IV | 10,436.31 | 4,180.87 | 14,617.18 | 28.60 |

The average time spent standing during the four periods was 925.75 minutes per day. In order to make the corrections as small as possible, the results have been computed to a uniform basis of 925 minutes standing. The correction computed in the same manner as in the foregoing experiments, the corrected amount of heat given off by radiation and conduction, and the corrected heat emission are shown in the following tables:

TABLE 194.—*Heat emission per day corrected to 925 minutes standing, 1903.*

| Periods. | Correction. | Corrected radiation and conduction. | Corrected total. |
|---|---|---|---|
| | *Calories.* | *Calories.* | *Calories.* |
| I | + 105.96 | 9,039.39 | 11,793.1 |
| II | + 34.12 | 7,511.67 | 10,133.1 |
| III | + 270.54 | 7,993.59 | 10,899.4 |
| IV | + 551.03 | 9,885.28 | 13,844.9 |

TABLE 195.—*Heat production corrected to 925 minutes standing, 1903.*

| Periods. | Corrected emission. | Correction for water balance. | Corrected heat production. |
|---|---|---|---|
| | *Calories.* | *Calories.* | *Calories.* |
| I | 11,793.1 | − 126.3 | 11,666.8 |
| II | 10,133.1 | + 36.6 | 10,169.7 |
| III | 10,899.4 | + 9.8 | 10,909.2 |
| IV | 13,844.9 | + 34.7 | 13,879.6 |

TABLE 196.—*Corrected gains of energy by animals, 1903.*

| | Income. | Outgo. |
|---|---|---|
| Period I: | *Calories.* | *Calories.* |
| Metabolizable | 8,449 | |
| Brushings | | 81 |
| Heat | | 11,667 |
| Gain | 3,299 | |
| | 11,748 | 11,748 |
| Period II: | | |
| Metabolizable | 6,154 | |
| Brushings | | 81 |
| Heat | | 10,170 |
| Gain | 4,097 | |
| | 10,251 | 10,251 |
| Period III: | | |
| Metabolizable | 8,238 | |
| Brushings | | 81 |
| Heat | | 10,899 |
| Gain | 2,742 | |
| | 10,980 | 10,980 |
| Period IV: | | |
| Metabolizable | 17,973 | |
| Brushings | | 81 |
| Heat | | 13,845 |
| Gain | | 4,047 |
| | 17,973 | 17,973 |

TABLE 197.—*Average live weights, 1903.*

| | Kilos. |
|---|---|
| Period I | 550.2 |
| Period II | 525.1 |
| Period III | 519.2 |
| Period IV | 525.9 |

TABLE 198.—*Availability of metabolizable energy of clover hay, Periods I–II.*

$$n=\left(\frac{525.1}{550.2}\right)^{2/3}=0.9694$$

$$x_2=6{,}154 \qquad y_2=-4{,}097$$
$$x_1=8{,}449 \qquad y_1=-3{,}299$$

$$m=\frac{-4{,}097-(0.9694\times-3{,}299)}{6{,}154-(0.9694\times8{,}454)}=44.04 \text{ per cent.}$$

TABLE 199.—*Correction for differences in amount of hay eaten.*

| Periods. | Organic matter of hay. | Metabolizable energy of total ration. | Gain by animal. |
|---|---|---|---|
| | *Grams.* | *Calories.* | *Calories.* |
| Period II | 2,940.8 | | |
| Period III | 2,952.8 | 8,238 | −2,742 |
| Correction | −12.0 | −25 | −11 |
| Period III, corrected | 2,940.8 | 8,213 | −2,753 |
| Period II | 2,940.8 | | |
| Period IV | 2,974.8 | 17,973 | 4,047 |
| Correction | −34.0 | −71 | −31 |
| Period IV, corrected | 2,940.8 | 17,902 | 4,016 |

TABLE 200.—*Availability of metabolizable energy of corn meal.*

PERIODS III-II.

$$n=\left(\frac{525.1}{519.2}\right)^{\frac{2}{3}}=1.008$$

$$x_2=6{,}154 \qquad y_2=-4{,}097$$
$$x_3=8{,}213 \qquad y_3=-2{,}753$$

$$m=\frac{-4{,}097-(1.008\times -2{,}753)}{6{,}154-(1.008\times 8{,}213)}=62.22 \text{ per cen}$$

PERIODS IV-II.

$$n=\left(\frac{525.1}{525.9}\right)^{\frac{2}{3}}=0.9991$$

$$x_2=6{,}154 \qquad y_2=-4{,}097$$
$$x_4=17{,}902 \qquad y_4=4{,}016$$

$$m=\frac{-4{,}097-(0.9991\times 4{,}016)}{6{,}154-(0.9991\times 17{,}902)}=69.12 \text{ per cent.}$$

PERIODS IV-III.

$$n=\left(\frac{519.2}{525.9}\right)^{\frac{2}{3}}=0.9915$$

$$x_3=8{,}213 \qquad y_3=-2{,}753$$
$$x_4=17{,}902 \qquad y_4=4{,}016$$

$$m=\frac{-2{,}753-(0.9915\times 4{,}016)}{8{,}213-(0.9915\times 17{,}902)}=70.83 \text{ per cent.}$$

## DIGESTION AND METABOLISM TRIALS DURING THE INTERMEDIATE FEEDING PERIODS.

As stated in Part I, pages 13 and 66–69, four digestion and metabolism experiments were made in the course of what have been designated as the intermediate feeding periods. Full data regarding the composition of the feeding stuffs used in these experiments are contained in Table 26 of Part I (p. 63). The details of the experiments follow, including some repetition of data already presented in Part I.

### DIGESTIBILITY OF THE RATIONS.

#### TRIAL OF DECEMBER 1-10, 1904.

The rations offered daily were identical with those consumed for the preceding month, but a considerable portion of the hay was rejected by the animals.

TABLE 201.—*Daily rations during digestion trial, December 1-10, 1904.*

| Feed. | Steer A. | Steer B. |
|---|---|---|
| | *Grams.* | *Grams.* |
| Mixed hay | 3,629 | 3,629 |
| Wheat bran | 254 | 180 |
| Corn meal | 761 | 540 |
| Old-process linseed meal | 761 | 540 |

During October and November long hay was fed. On November 26, 1904, a portion of the same hay was cut for the digestion trials and duplicate samples were taken in which the composition of the dry matter was determined. The average of these two analyses is regarded as representing the composition of the dry matter of the hay used in the digestion experiment and also of that previously fed.

On November 28, when the feeds were weighed out for the digestion experiment, a second sample was taken in which only the loss in air drying and the nitrogen were determined. The percentage of moisture in the dry-air matter has been computed on the assumption that the nitrogen content of the dry matter was the same as the average of the two previous samples.

In the samples of grain taken during this period, the determination of the moisture in the air-dry material was overlooked. The percentage given in Table 26 of Part I is estimated from that found in similar samples in these and previous experiments. The close agreement of the percentages of total nitrogen in the dry matter as computed on this basis indicates its substantial correctness. It may be noted also that this error does not affect the determination of the total amount of nitrogen consumed and therefore does not affect the nitrogen balance subsequently computed. On this basis, the composition of the feeding stuffs used was as follows:

TABLE 202.—*Composition of feeding stuffs in digestion trial, December 1–10, 1904.*

| Component. | Mixed hay. | Wheat bran. | Corn meal. | Old-process linseed meal. |
|---|---|---|---|---|
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Water | 17.58 | 16.64 | 13.61 | 11.51 |
| Dry matter | 82.42 | 83.36 | 86.39 | 88.49 |
| | 100.00 | 100.00 | 100.00 | 100.00 |
| In dry matter: | | | | |
| Ash | 8.01 | 1.52 | 8.81 | 5.78 |
| Protein | 13.04 | 9.65 | 14.94 | 30.46 |
| Nonprotein | | | | |
| Crude fiber | 28.27 | 1.84 | 10.55 | 9.39 |
| Nitrogen-free extract | 50.68 | 86.99 | 65.70 | 54.37 |
| Ether extract | | | | |
| Estimated nonprotein (average) | 1.46 | .39 | 2.20 | 4.39 |

The live weights of the animals, the weights of water consumed and excreta collected, and the composition of the dry matter of the feces are contained in Tables XI and XII of the appendix. From these data the results as regards the digestibility of the ration are computed in the following table. While the energy of the feeds and feces was not determined, the results in the other three trials are so uniform that it appears safe to apply their average to the computation of this experiment. These averages are:

*Average energy per gram dry matter.*

| | Calories. |
|---|---|
| Mixed hay | 4.5159 |
| Wheat bran | 4.5432 |
| Corn meal [1] | 4.4425 |
| Linseed meal | 4.8908 |
| Feces | 4.7201 |

TABLE 203.—*Feed and excreta, December 1-10, 1904.*

| | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of days. | Fresh weight. | Dry matter. | | Number of days. | Fresh weight. | Dry matter. | |
| | | *Grams.* | *Per cent.* | *Grams.* | | *Grams.* | *Per cent.* | *Grams.* |
| Mixed hay: | | | | | | | | |
| Total | 10 | 36,290.0 | 82.42 | 29,910.2 | 10 | 36,290.0 | 82.42 | 29,910.2 |
| Uneaten | | 12,367.0 | 83.83 | 10,367.3 | | 5,086.0 | 84.23 | 4,283.9 |
| Eaten | | 24,923.0 | | 19,542.9 | | 31,204.0 | | 25,626.3 |
| Eaten per day | | 2,492.3 | | 1,954.3 | | 3120.4 | | 2,562.6 |
| Wheat bran: | | | | | | | | |
| Total | 10 | 2,540.0 | 86.39 | 2,194.3 | 10 | 1,800.0 | 86.39 | 1,555.0 |
| Eaten per day | | 254.0 | | 219.4 | | 180.0 | | 155.5 |
| Corn meal: | | | | | | | | |
| Total | 10 | 7,610.0 | 83.36 | 6,343.7 | 10 | 5,400.0 | 83.36 | 4,501.4 |
| Eaten per day | | 761.0 | | 634.4 | | 540.0 | | 450.1 |
| Old-process linseed meal: | | | | | | | | |
| Total | 10 | 7,610.0 | 88.49 | 6,734.1 | 10 | 5,400.0 | 88.49 | 4,778.5 |
| Eaten per day | | 761.0 | | 673.4 | | 540.0 | | 477.9 |
| Feces: | | | | | | | | |
| Collected | 10 | 83,720.0 | 18.08 | 15,139.1 | 10 | 79,650.0 | 19.51 | 15,539.7 |
| In duct | | 980.0 | 18.08 | 177.2 | | 535.0 | 19.51 | 104.4 |
| Total | | | | 15,316.3 | | 80,185.0 | | 15,644.1 |
| Excreted per day | | | | 1,531.6 | | 8,018.5 | | 1,564.4 |

TABLE 204.—*Digestibility of rations, December 1-10, 1904.*

| | Dry matter. | Ash. | Organic matter. | Crude protein. | Non-protein. | Crude fiber. | Nitrogen-free and ether extracts. | Total nitrogen. | Computed energy. |
|---|---|---|---|---|---|---|---|---|---|
| *Steer A.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Calories.* |
| Mixed hay | 2,991.0 | 239.6 | 2,751.4 | 390.0 | 43.7 | 845.6 | 1,515.8 | 62.5 | 13,507.1 |
| Wheat bran | 219.4 | 19.3 | 200.1 | 32.8 | 4.8 | 23.1 | 144.2 | 5.8 | 996.8 |
| Corn meal | 634.4 | 9.6 | 624.8 | 61.2 | 2.5 | 11.7 | 551.9 | 10.2 | 2,818.3 |
| Linseed meal | 673.4 | 38.9 | 634.5 | 205.1 | 29.6 | 63.2 | 366.2 | 37.3 | 3,293.5 |
| Total | 4,518.2 | 307.4 | 4,210.8 | 689.1 | 80.6 | 943.6 | 2,578.1 | 115.8 | 20,615.7 |
| Refused | 1,036.7 | 123.6 | 913.1 | 197.6 | 15.1 | 145.6 | 569.9 | 31.6 | 4,681.6 |
| Eaten | 3,481.5 | 183.8 | 3,297.7 | 491.5 | 65.5 | 798.0 | 2,008.2 | 84.2 | 15,934.1 |
| Feces | 1,531.6 | 151.0 | 1,380.6 | 274.8 | | 443.2 | 662.6 | 44.0 | 7,229.3 |
| Digested | 1,949.9 | 32.8 | 1,917.1 | 216.7 | 65.5 | 354.8 | 1,345.6 | 40.2 | 8,704.8 |
| Percentage digestibility | 56.01 | 17.85 | 58.13 | 44.09 | 100.00 | 44.46 | 67.00 | 47.74 | 54.63 |
| *Steer B.* | | | | | | | | | |
| Mixed hay | 2,991.0 | 239.6 | 2,751.4 | 390.0 | 43.7 | 845.6 | 1,515.8 | 62.5 | 13,507.1 |
| Wheat bran | 155.5 | 13.7 | 141.8 | 23.2 | 3.4 | 16.4 | 102.2 | 4.1 | 706.5 |
| Corn meal | 450.1 | 6.8 | 443.3 | 43.4 | 1.8 | 8.3 | 391.5 | 7.2 | 1,999.6 |
| Linseed meal | 477.9 | 27.6 | 450.3 | 145.6 | 21.0 | 44.9 | 259.8 | 26.5 | 2,337.3 |
| Total | 4,074.5 | 287.7 | 3,786.8 | 602.2 | 69.9 | 915.2 | 2,269.3 | 100.3 | 18,550.5 |
| Refused | 428.4 | 44.8 | 383.6 | 85.4 | 6.3 | 43.4 | 254.7 | 13.7 | 1,934.6 |
| Eaten | 3,646.1 | 242.9 | 3,403.2 | 516.8 | 63.6 | 871.8 | 2,014.6 | 86.6 | 16,615.9 |
| Feces | 1,564.4 | 155.0 | 1,409.4 | 256.2 | | 477.0 | 676.2 | 41.0 | 7,384.1 |
| Digested | 2,081.7 | 87.9 | 1,993.8 | 260.6 | 63.6 | 394.8 | 1,338.4 | 45.6 | 9,231.8 |
| Percentage digestibility. | 57.09 | 36.19 | 58.59 | 50.43 | 100.00 | 45.29 | 66.44 | 52.66 | 55.56 |

[1] Average of second and third trials only.

The percentage digestibility of the total ration appears low as compared with the results obtained in subsequent periods in which approximately the same proportion of hay and grain was consumed. As will appear subsequently, the nitrogen balance indicates some serious error in the work and the results of this trial should therefore be accepted with considerable reserve.

### TRIAL OF JULY 6–15, 1905.

The feeding stuffs for this experiment were weighed out on June 28 and samples taken at the same time, the composition of which is shown in the following table:

TABLE 205.—*Composition of feeding stuffs in digestion trial, July 6–15, 1905.*

| Component and energy. | Mixed hay. | Wheat bran. | Corn meal. | Old-process linseed meal. |
|---|---|---|---|---|
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Water | 15.75 | 11.30 | 12.97 | 9.15 |
| Dry matter | 84.25 | 88.70 | 87.03 | 90.85 |
| | 100.00 | 100.00 | 100.00 | 100.00 |
| In dry matter: | | | | |
| Ash | 6.69 | 7.02 | 1.48 | 5.67 |
| Protein[1] | 12.25 | 12.54 | 8.22 | 27.21 |
| Nonprotein[1] | 1.22 | 2.12 | .61 | 2.93 |
| Crude fiber | 30.39 | 10.13 | 2.40 | 9.46 |
| Nitrogen-free extract | 46.09 | 63.02 | 83.69 | 47.07 |
| Ether extract | 3.36 | 5.17 | 3.60 | 7.66 |
| | 100.00 | 100.00 | 100.00 | 100.00 |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Energy per gram dry matter | 4.5940 | 4.5841 | 4.4773 | 4.9244 |

[1] Computed from nitrogen, using the factors stated in Part III, page 203.

While the preliminary period covered only 5 days, viz, July 1–5, the daily grain ration for 34 days previous had differed only 20 grams in the case of steer A and only 5 grams in the case of steer B from the amounts weighed out for the digestion period. For the same 34 days, the average hay consumed was, by steer A, 3,120 grams, and by steer B 2,990 grams. The rations during the digestion trial were:

TABLE 206.—*Daily rations during digestion trial, July 6-15, 1905.*

| Feed. | Steer A. | Steer B. |
|---|---|---|
| | *Grams.* | *Grams.* |
| Mixed hay | 2,800 | 2,800 |
| Wheat bran | 360 | 285 |
| Corn meal | 1,080 | 855 |
| Old-process linseed meal | 1,080 | 855 |

From the foregoing data and from the records of the appendix, the following results as regards digestibility are computed:

TABLE 207.—*Feed and excreta, July 6-15, 1905.*

| | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of days. | Fresh weight. | Dry matter. | | Number of days. | Fresh weight. | Dry matter. | |
| | | *Grams.* | *Per cent.* | *Grams.* | | *Grams.* | *Per cent.* | *Grams.* |
| Mixed hay: | | | | | | | | |
| Total | 10 | 28,000.0 | 84.17 | 23,567.6 | 10 | 28,000.0 | 84.17 | 23,567.6 |
| Eaten per day | | 2,800.0 | | 2,356.8 | | 2,800.0 | | 2,356.8 |
| Wheat bran: | | | | | | | | |
| Total | 10 | 3,600.0 | 88.70 | 3,193.2 | 10 | 2,850.0 | 88.70 | 2,527.95 |
| Eaten per day | | 360.0 | | 319.3 | | 285.0 | | 252.8 |
| Corn meal: | | | | | | | | |
| Total | 10 | 10,800.0 | 87.03 | 9,399.2 | 10 | 8,550.0 | 87.03 | 7,441.06 |
| Eaten per day | | 1,080.0 | | 939.9 | | 855.0 | | 744.1 |
| Linseed meal: | | | | | | | | |
| Total | 10 | 10,800.0 | 90.85 | 9,811.8 | 10 | 8,550.0 | 90.85 | 7,767.7 |
| Eaten per day | | 1,080.0 | | 981.2 | | 855.0 | | 776.8 |
| Feces: | | | | | | | | |
| Collected | 9 | 72,995.0 | 19.41 | 14,168.3 | 10 | 73,100.0 | 16.16 | 12,141.9 |
| Spilled, July 7 | | | | 30.0 | | | | |
| In duct | 10 | | | 80.0 | | | | 68.0 |
| Total | | | | 14,278.3 | | | | 12,209.9 |
| Excreted per day | | | | 1,585.6 | | | | 1,221.0 |

TABLE 208.—*Digestibility of rations, July 6-15, 1905.*

| | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|
| *Steer A.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Calories.* |
| Hay | 2,356.8 | 157.7 | 2,199.1 | 288.7 | 28.8 | 716.2 | 1,086.2 | 79.2 | 52.3 | 10,827.1 |
| Bran | 319.3 | 22.4 | 296.9 | 40.0 | 6.8 | 32.3 | 201.3 | 16.5 | 8.5 | 1,463.7 |
| Corn meal | 939.9 | 13.9 | 926.0 | 77.3 | 5.7 | 22.6 | 786.6 | 33.8 | 14.0 | 4,208.2 |
| Linseed meal | 981.2 | 55.6 | 925.6 | 267.0 | 28.7 | 92.8 | 461.9 | 75.2 | 53.5 | 4,831.8 |
| Total | 4,597.2 | 249.6 | 4,347.6 | 673.0 | 70.0 | 863.9 | 2,536.0 | 204.7 | 128.3 | 21,330.8 |
| Feces | 1,585.3 | 153.1 | 1,432.2 | 270.0 | | 536.5 | 578.6 | 47.1 | 43.2 | 7,574.2 |
| Digested | 3,011.9 | 96.5 | 2,915.4 | 403.0 | 70.0 | 327.4 | 1,957.4 | 157.6 | 85.1 | 13,756.6 |
| Percentage digestibility | 65.52 | 38.66 | 67.06 | 59.88 | 100.00 | 37.90 | 77.18 | 76.99 | 66.33 | 64.49 |
| *Steer B.* | | | | | | | | | | |
| Hay | 2,356.8 | 157.7 | 2,199.1 | 288.7 | 28.8 | 716.2 | 1,086.2 | 79.2 | 52.3 | 10,827.1 |
| Bran | 252.8 | 17.7 | 235.1 | 31.7 | 5.4 | 25.6 | 159.3 | 13.1 | 6.7 | 1,158.9 |
| Corn meal | 744.1 | 11.0 | 733.1 | 61.2 | 4.5 | 17.9 | 622.7 | 26.8 | 11.1 | 3,331.6 |
| Linseed meal | 776.8 | 44.0 | 732.8 | 211.4 | 22.8 | 73.5 | 365.6 | 59.5 | 42.3 | 3,825.3 |
| Total | 4,130.5 | 230.4 | 3,900.1 | 593.0 | 61.5 | 833.2 | 2,233.8 | 178.6 | 112.4 | 19,142.9 |
| Feces | 1,221.0 | 117.9 | 1,103.1 | 244.0 | | 384.7 | 437.6 | 36.8 | 39.0 | 5,852.1 |
| Digested | 2,909.5 | 112.5 | 2,797.0 | 349.0 | 61.5 | 448.5 | 1,796.2 | 141.8 | 73.4 | 13,290.8 |
| Percentage digestibility | 70.44 | 48.83 | 71.72 | 58.85 | 100.00 | 53.83 | 80.41 | 79.40 | 65.30 | 69.43 |

### TRIAL OF NOVEMBER 13-22, 1905.

The grain for this trial was weighed out and sampled November 4 and the hay on November 6. The feeding began November 8, and the collection of excreta on November 13. The rations consumed were as follows:

TABLE 209.—*Daily rations during digestion trial, November 13-22, 1905.*

| Feed. | Steer A. | Steer B. |
|---|---|---|
| | *Grams.* | *Grams.* |
| Mixed hay | 3,440 | 3,600 |
| Wheat bran | 360 | 285 |
| Corn meal | 1,080 | 855 |
| New-process linseed meal | 1,080 | 855 |

Practically the same amount of the same grain mixture (2,500 grams) had been fed daily since the previous digestion experiment in July. After the use of green crops during the summer had been discontinued the animals received hay beginning October 6, the average amounts consumed daily up to November 8 being, steer A, 3,300 grams; steer B, 3,130 grams.

The composition of the feeding stuffs is shown in the following table:

TABLE 210.—*Composition of feeding stuffs in digestion trial, November 13-22, 1905.*

| Component and energy. | Mixed hay. | Wheat bran. | Corn meal. | New-process linseed meal. |
|---|---|---|---|---|
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Water | 12.37 | 12.34 | 12.97 | 9.48 |
| Dry matter | 87.63 | 87.66 | 87.03 | 90.52 |
| | 100.00 | 100.00 | 100.00 | 100.00 |
| In dry matter: | | | | |
| Ash | 5.98 | 7.08 | 1.39 | 4.91 |
| Protein [1] | 8.26 | 13.38 | 8.99 | 29.87 |
| Nonprotein [1] | 2.14 | 2.32 | 0.30 | 3.58 |
| Crude fiber | 31.70 | 9.70 | 2.27 | 8.00 |
| Nitrogen-free extract | 48.83 | 63.58 | 84.14 | 52.15 |
| Ether extract | 3.09 | 3.94 | 2.91 | 1.49 |
| | 100.00 | 100.00 | 100.00 | 100.00 |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Energy per gram dry matter | 4.5005 | 4.5058 | 4.4077 | 4.7838 |

[1] Computed from nitrogen, using the factors stated in Part III, page 203.

**TABLE 211.**—*Feed and excreta, November 13–22, 1905.*

| | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of days. | Fresh weight. | Dry matter. | | Number of days. | Fresh weight. | Dry matter. | |
| | | *Grams.* | *Per cent.* | *Grams.* | | *Grams.* | *Per cent.* | *Grams.* |
| Timothy hay: | | | | | | | | |
| Total | 10 | 34,400.0 | 87.63 | 30,144.4 | 10 | 36,000.0 | 87.63 | 31,546.4 |
| Eaten per day | | 3,440.0 | | 3,014.4 | | 3,600.0 | | 3,154.6 |
| Wheat bran: | | | | | | | | |
| Total | 10 | 3,600.0 | 87.66 | 3,155.8 | 10 | 2,850.0 | 87.66 | 2,498.3 |
| Eaten per day | | 360.0 | | 315.6 | | 285.0 | | 249.8 |
| Corn meal: | | | | | | | | |
| Total | 10 | 10,800.0 | 87.03 | 9,399.7 | 10 | 8,550.0 | 87.03 | 7,441.4 |
| Eaten per day | | 1,080.0 | | 940.0 | | 855.0 | | 744.1 |
| Linseed meal: | | | | | | | | |
| Total | 10 | 10,800.0 | 90.52 | 9,776.4 | 10 | 8,550.0 | 90.52 | 7,739.6 |
| Eaten per day | | 1,080.0 | | 977.6 | | 855.0 | | 774.0 |
| Feces: | | | | | | | | |
| Collected | 10 | 103,170.0 | 16.93 | 17,470.8 | 9 | 75,580.0 | 19.84 | 14,997.3 |
| In duct | | | | 134.8 | 10 | | | 55.5 |
| Total | | | | 17,605.6 | | | | 15,052.8 |
| Excreted per day | | 10,317.0 | | 1,760.6 | | | | 1,672.0 |

**TABLE 212.**—*Digestibility of rations, November 13–22, 1905.*

| | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|
| *Steer A.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Calories.* |
| Timothy hay | 3,014.4 | 180.4 | 2,834.0 | 249.1 | 64.4 | 955.4 | 1,472.1 | 93.0 | 47.2 | 13,566.3 |
| Wheat bran | 315.6 | 22.4 | 293.2 | 42.2 | 7.8 | 30.6 | 200.7 | 12.4 | 9.0 | 1,422.0 |
| Corn meal | 940.0 | 13.1 | 926.9 | 84.5 | 2.8 | 21.3 | 791.0 | 27.3 | 14.7 | 4,143.2 |
| Linseed meal | 977.6 | 48.0 | 929.6 | 292.0 | 35.0 | 78.2 | 509.8 | 14.6 | 60.5 | 4,676.6 |
| Total | 5,247.6 | 263.9 | 4,983.7 | 667.8 | 109.5 | 1,085.5 | 2,973.6 | 147.3 | 131.4 | 23,808.1 |
| Feces | 1,760.6 | 178.0 | 1,582.6 | 261.2 | | 465.1 | 816.5 | 39.8 | 41.8 | 8,198.2 |
| Digested | 3,487.0 | 85.9 | 3,401.1 | 406.6 | 109.5 | 620.4 | 2,157.1 | 107.5 | 89.6 | 15,609.9 |
| Percentage digestibility | 66.45 | 32.55 | 68.24 | 60.89 | 100.00 | 57.16 | 72.54 | 72.98 | 68.19 | 65.56 |
| *Steer B.* | | | | | | | | | | |
| Timothy hay | 3,154.6 | 188.7 | 2,965.9 | 260.7 | 67.4 | 999.9 | 1,540.5 | 97.4 | 49.3 | 14,197.3 |
| Wheat bran | 249.8 | 17.7 | 232.1 | 33.4 | 5.8 | 24.2 | 158.8 | 9.8 | 7.1 | 1,125.5 |
| Corn meal | 744.1 | 10.4 | 733.7 | 66.9 | 2.2 | 16.9 | 626.1 | 21.6 | 11.6 | 3,279.8 |
| Linseed meal | 774.0 | 38.0 | 736.0 | 231.2 | 27.7 | 61.9 | 403.7 | 11.6 | 47.9 | 3,702.7 |
| Total | 4,922.5 | 254.8 | 4,667.7 | 592.2 | 103.1 | 1,102.9 | 2,729.1 | 140.4 | 115.9 | 22,305.3 |
| Feces | 1,672.0 | 170.6 | 1,501.4 | 229.1 | | 487.2 | 746.4 | 38.7 | 36.7 | 7,739.6 |
| Digested | 3,250.5 | 84.2 | 3,166.3 | 363.1 | 103.1 | 615.7 | 1,982.7 | 101.7 | 79.2 | 14,565.7 |
| Percentage digestibility | 66.03 | 33.05 | 67.83 | 61.31 | 100.00 | 55.83 | 72.65 | 72.44 | 68.33 | 65.30 |

### TRIAL OF JUNE 27–JULY 6, 1906.

The grain for the digestion trial was weighed out on June 16 and the hay on June 18, the composition of the samples taken at that time being as shown in the table below. The amounts consumed daily were:

TABLE 213.—*Daily rations during digestion trial, June 27–July 6, 1906.*

| Feed. | Steer A. | Steer B. |
|---|---|---|
| | *Grams.* | *Grams.* |
| Mixed hay | 5,120 | 4,080 |
| Wheat bran | 635 | 460 |
| Corn-and-cob meal | 1,905 | 1,380 |
| Old-process linseed meal | 635 | 460 |

The feeding of this exact ration was begun on June 20. The daily grain ration, however, had been the same in amount since June 1 and during the same time the daily hay consumed was by steer A 4,980 grams, and by steer B 4,000 grams.

TABLE 214.—*Composition of feeding stuffs in digestion trial, June 27–July 6, 1906.*

| Component and energy. | Mixed hay. | Wheat bran. | Corn-and-cob meal. | Old-process linseed meal. |
|---|---|---|---|---|
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Water | 13.29 | 13.44 | 13.87 | 11.95 |
| Dry matter | 86.71 | 86.56 | 86.13 | 88.05 |
| | 100.00 | 100.00 | 100.00 | 100.00 |
| In dry matter: | | | | |
| Ash | 7.12 | 7.56 | 1.76 | 5.62 |
| Protein [1] | 11.14 | 14.56 | 8.54 | 26.05 |
| Nonprotein [1] | 1.20 | 2.15 | .26 | 6.66 |
| Crude fiber | 30.04 | 9.65 | 8.41 | 9.09 |
| Nitrogen-free extract | 47.91 | 61.07 | 77.14 | 44.56 |
| Ether extract | 2.59 | 5.01 | 3.89 | 8.02 |
| | 100.00 | 100.00 | 100.00 | 100.00 |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Energy per gram dry matter | 4.4531 | 4.5397 | 4.5233 | 4.9642 |

[1] Computed from nitrogen, using the factors stated in Part III, page 203.

TABLE 215.—*Feed and excreta, June 27–July 6, 1906.*

| | Steer A. | | | | Steer B. | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of days. | Fresh weight. | Dry matter. | | Number of days. | Fresh weight. | Dry matter. | |
| Mixed hay: | | *Grams.* | *Per cent.* | *Grams.* | | *Grams.* | *Per cent.* | *Grams.* |
| Total | 10 | 51,200.0 | 86.71 | 44,394.0 | 10 | 40,800.0 | 86.71 | 35,376.5 |
| Eaten per day | | 5,120.0 | | 4,439.4 | | 4,080.0 | | 3,537.7 |
| Wheat bran: | | | | | | | | |
| Total | 10 | 6,350.0 | 86.56 | 5,496.4 | 10 | 4,600.0 | 86.56 | 3,981.6 |
| Eaten per day | | 635.0 | | 549.6 | | 460.0 | | 398.2 |
| Corn meal: | | | | | | | | |
| Total | 10 | 19,050.0 | 86.13 | 16,406.8 | 10 | 13,800.0 | 86.13 | 11,885.3 |
| Eaten per day | | 1,905.0 | | 1,640.7 | | 1,380.0 | | 1,188.5 |
| Linseed meal: | | | | | | | | |
| Total | 10 | 6,350.0 | 88.05 | 5,591.4 | 10 | 4,600.0 | 88.05 | 4,050.5 |
| Eaten per day | | 635.0 | | 559.1 | | 460.0 | | 405.0 |
| Feces: | | | | | | | | |
| Collected | 10 | 167,505.0 | 14.42 | 24,160.9 | 10 | 94,045.0 | 19.65 | 18,478.9 |
| In duct | | 1,913.0 | 14.42 | 275.8 | | 934.0 | 18.31 | 171.0 |
| Total | | 169,418.0 | | 24,436.7 | | 94,979.0 | 37.96 | 18,649.9 |
| Excreted per day | | 16,941.8 | | 2,443.7 | | 9,497.9 | | 1,864.9 |

TABLE 216.—*Digestibility of rations, June 27–July 6, 1906.*

| | Dry matter. | Ash. | Organic matter. | Protein. | Non-protein. | Crude fiber. | Nitrogen-free extract. | Ether extract. | Total nitrogen. | Energy. |
|---|---|---|---|---|---|---|---|---|---|---|
| *Steer A.* | | | | | | | | | | |
| | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Calories.* |
| Mixed hay..... | 4,439.4 | 316.1 | 4,123.3 | 494.5 | 53.3 | 1,333.6 | 2,126.9 | 115.0 | 90.5 | 19,769.1 |
| Wheat bran.... | 549.6 | 41.5 | 508.1 | 80.0 | 11.8 | 53.0 | 335.8 | 27.5 | 16.6 | 2,495.0 |
| Corn chop...... | 1,640.7 | 28.9 | 1,611.8 | 140.1 | 4.3 | 138.0 | 1,265.6 | 63.8 | 24.2 | 7,421.4 |
| Linseed meal... | 559.1 | 31.4 | 527.7 | 145.6 | 37.2 | 50.8 | 249.3 | 44.8 | 34.4 | 2,775.5 |
| Total..... | 7,188.8 | 417.9 | 6,770.9 | 860.2 | 106.6 | 1,575.4 | 3,977.6 | 251.1 | 165.7 | 32,461.0 |
| Feces.......... | 2,443.7 | 226.5 | 2,217.2 | 409.8 | ........ | 763.4 | 987.6 | 56.4 | 65.6 | 11,436.3 |
| Digested. | 4,745.1 | 191.4 | 4,553.7 | 450.4 | 106.6 | 812.0 | 2,990.0 | 194.7 | 100.1 | 21,024.7 |
| Percentage digestibility.... | 66.01 | 45.80 | 67.25 | 52.36 | 100.00 | 51.54 | 75.17 | 77.54 | 60.41 | 64.77 |
| *Steer B.* | | | | | | | | | | |
| Mixed hay..... | 3,537.6 | 251.9 | 3,285.7 | 394.1 | 42.5 | 1,062.7 | 1,694.8 | 91.6 | 72.1 | 15,753.3 |
| Wheat bran.... | 398.2 | 30.1 | 368.1 | 58.0 | 8.6 | 38.4 | 243.2 | 19.9 | 12.0 | 1,807.7 |
| Corn-and-cob meal.......... | 1,188.5 | 20.9 | 1,167.6 | 101.5 | 3.1 | 100.0 | 916.8 | 46.2 | 17.6 | 5,375.9 |
| Linseed meal... | 405.0 | 22.8 | 382.2 | 105.5 | 27.0 | 36.8 | 180.4 | 32.5 | 24.9 | 2,010.5 |
| Total..... | 5,529.3 | 325.7 | 5,203.6 | 659.1 | 81.2 | 1,237.9 | 3,035.2 | 190.2 | 126.6 | 24,947.4 |
| Feces.......... | 1,864.9 | 179.6 | 1,685.3 | 278.2 | ........ | 578.1 | 780.4 | 48.6 | 44.5 | 8,884.2 |
| Digested. | 3,664.4 | 146.1 | 3,518.3 | 380.9 | 81.2 | 659.8 | 2,254.8 | 141.6 | 82.1 | 16,063.2 |
| Percentage digestibility.... | 66.27 | 44.86 | 67.61 | 57.79 | 100.00 | 53.30 | 74.29 | 74.45 | 64.85 | 64.39 |

## NITROGEN BALANCES.

During the several digestion trials described above, the urine of the animals was also collected quantitatively and its percentage of nitrogen, and in two cases its content of potential energy, determined. Table XI of the appendix records the daily excretion in each period and the corresponding amounts of nitrogen. In the first three trials the amount of nitrogen excreted was determined by an analysis of a composite sample made by taking one-fiftieth of the amount excreted each day. In the fourth trial, a nitrogen determination was made in each daily sample, a check determination being also made upon a composite sample taken as above described. The close agreement of the results obtained by the two methods attests the accuracy of the work and indicates that the results obtained in the three previous trials are in all probability substantially accurate.

It is evident, however, that there is some undiscovered source of error in the first of these trials. The animals were transferred from the barn to the calorimeter building very shortly before the beginning of the digestion period, and during the entire period were apparently somewhat disturbed by their new surroundings and failed to eat a normal amount. This was especially the case with steer A, as shown by the large uneaten residues, consisting in part of grain as well as of hay. Even after making all allowance for this disturbing element, however, the percentage digestibility in both cases, as already noted, seems abnormally low, while the nitrogen balance shows such a large loss of nitrogen from the body as to raise a suspicion of some undiscovered error in weighing or analysis. While no such error is apparent upon the face of the records, it is evident nevertheless that the results of this experiment must be looked upon with considerable suspicion.

In the digestion trial of June 27 to July 6, 1906, the records show that the daily excretion of urinary nitrogen increased toward the end of the trial with both animals, suggesting the influence of some external cause, although none was apparent. It is possible, therefore, that the computed gains of protein in this trial are too small.

The data for nitrogen do not include determinations of that contained in the growth of epidermal tissue, while in the respiration calorimeter experiments the latter was determined and entered separately in the nitrogen balance. Obviously this is the proper method, since the growth of these tissues goes on more or less independently of the state of nutrition of the animal, and the immediate effect of the feed is more accurately measured by the gain or loss of the other nitrogenous tissues.

The average amount of nitrogen in the daily growth of epidermal tissue in the three series of respiration calorimeter experiments as determined and also as computed to the uniform live weight of 500 kilograms in proportion to the relative surfaces of the animal, that is, to the two-thirds power of the live weight, was as follows:

TABLE 217.—*Nitrogen in average daily growth of epidermal tissue in respiration calorimeter experiments.*

| | Steer A. | | | Steer B. | | |
|---|---|---|---|---|---|---|
| | Average live weight.[1] | Nitrogen. | | Average live weight.[1] | Nitrogen. | |
| | | Per head. | Per 500 kilos live weight. | | Per head. | Per 500 kilos live weight. |
| | *Kilos.* | *Grams.* | *Grams.* | *Kilos.* | *Grams.* | *Grams.* |
| 1905 | 274.0 | 1.74 | 2.60 | 194.8 | 1.17 | 2.19 |
| 1906 | 407.6 | 1.62 | 1.86 | 303.1 | 1.30 | 1.82 |
| 1907 | 509.7 | 1.90 | 1.88 | 379.4 | 1.74 | 2.09 |
| Average | | | 2.11 | | | 2.03 |

[1] Mean of the averages computed for each of the respiration calorimeter experiments separately.

Applying the average figure of 2.07 grams per 500 kilograms live weight for the nitrogen in the epidermal tissue to the live weights of the animals in the metabolism trials, we may compute the average nitrogen in their daily growth of epidermal tissue as follows:

TABLE 218.—*Computed nitrogen in daily growth of epidermal tissue in digestion trials.*

| Periods. | Steer A. | | Steer B. | |
|---|---|---|---|---|
| | Average live weight. | Nitrogen per head. | Average live weight. | Nitrogen per head. |
| | *Kilos.* | *Grams.* | *Kilos.* | *Grams.* |
| Dec. 1 to 10, 1904 | 278.3 | 1.40 | 215.5 | 1.18 |
| July 6 to 15, 1905 | 312.3 | 1.51 | 232.4 | 1.24 |
| Nov. 13 to 22, 1905 | 379.3 | 1.72 | 288.0 | 1.43 |
| June 27 to July 6, 1906 | 451.4 | 1.93 | 340.9 | 1.60 |

Including the foregoing estimates, the nitrogen balances in these trials are as follows:

TABLE 219.—*Nitrogen balance per day and head in digestion trials.*

| | Dec. 1-10, 1904. | | July 6-15, 1905. | | Nov. 13-22, 1905. | | June 27-July 6, 1906. | |
|---|---|---|---|---|---|---|---|---|
| | Nitrogen of feed. | Nitrogen of excreta. | Nitrogen of feed. | Nitrogen of excreta. | Nitrogen of feed. | Nitrogen of excreta. | Nitrogen of feed. | Nitrogen of excreta. |
| *Steer A.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Grams.* |
| Mixed hay | 62.5 | | 52.3 | | 47.2 | | 90.5 | |
| Wheat bran | 5.8 | | 8.5 | | 9.0 | | 16.6 | |
| Corn meal | 10.2 | | 14.0 | | 14.7 | | 24.2 | |
| Linseed meal | 37.3 | | 53.5 | | 60.5 | | 34.4 | |
| Uneaten feed | | 31.6 | | | | | | |
| Feces | | 44.0 | | 43.2 | | 41.8 | | 65.6 |
| Urine | | 78.5 | | 79.1 | | 85.0 | | [1] 99.7 |
| Hair and brushings (estimated) | | 1.4 | | 1.5 | | 1.7 | | 1.9 |
| Balance | 39.7 | | | 4.4 | | 2.9 | 1.5 | |
| | 155.5 | 155.5 | 128.2 | 128.2 | 131.4 | 131.4 | 167.2 | 167.2 |
| *Steer B.* | | | | | | | | |
| Mixed hay | 62.5 | | 52.3 | | 49.3 | | 72.1 | |
| Wheat bran | 4.1 | | 6.7 | | 7.1 | | 12.0 | |
| Corn meal | 7.2 | | 11.1 | | 11.6 | | 17.6 | |
| Linseed meal | 26.5 | | 42.3 | | 47.9 | | 24.9 | |
| Uneaten feed | | 13.7 | | | | | | |
| Feces | | 41.0 | | 39.0 | | 36.7 | | 44.5 |
| Urine | | 69.8 | | 65.9 | | 72.4 | | [1] 77.9 |
| Hair and brushings (estimated) | | 1.2 | | 1.2 | | 1.4 | | 1.6 |
| Balance | 25.4 | | | 6.3 | | 5.4 | | 2.6 |
| | 125.7 | 125.7 | 112.4 | 112.4 | 115.9 | 115.9 | 126.6 | 126.6 |

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[1] The records of both steers, but especially of steer A, show increase of urinary nitrogen in later days of period.

## PART III. EXPERIMENTAL METHODS.

For the convenience of the reader, and to avoid needless repetitions in the body of the article, the following summary of the experimental methods used in these investigations is presented:

### RECORDS OF ANIMALS.

The quantitative collection of the excreta in the respiration calorimeter experiments and also in the digestion and metabolism trials was conducted in the special stalls contained in the respiration calorimeter building. In the respiration calorimeter experiments each period covered three weeks, of which the first 11 days were regarded as the preliminary feeding. During the larger part of the latter the animals were kept in the barn of the experiment station, partly in a box stall and in part in an open yard where no feed was accessible, the object being to allow more freedom of motion and to maintain their health. In some cases, as shown in the account of the experiments, a transition feeding was introduced between two periods, which lengthened the time spent at the barn by a week. The digestion trials included in the intermediate feeding periods were made as nearly as possible upon the average ration of the preceding month, and consequently only a short preliminary feeding was observed.

*Live weight.*—Except on the days of the respiration calorimeter experiments, the weights of the animals were taken at 1 p. m., 24 hours after the last watering, on scales sensitive to about 0.1 kilogram.

*Water consumed.*—Water at a temperature of 15°–16° C. was offered once daily, immediately after weighing, the amount not being limited. Immediately after drinking, the animals were reweighed, the difference between the two weighings being regarded as representing the water consumed.

*Rectal temperature.*—The rectal temperature was taken immediately before watering and also immediately before entering and after leaving the calorimeter.

*Measurements.*—The measurements recorded in Table I of the appendix were taken by means of a tape line and calipers. They were not of the highest degree of accuracy, but it is thought that they were sufficiently exact for the purpose, which was to give a general picture of the rate of increase in the size of the two animals.

### FEEDING STUFFS.

#### GRAIN.

The total supply of each grain required for a period was thoroughly mixed and the entire quantity spread out in a thin layer on a tight floor. It was then divided in quarters and the two opposite quarters of the mass removed, care being taken to secure all of the material. The portion thus taken was thoroughly mixed and resampled in the same way, the operation being repeated as many times as necessary to secure a manageable sample. Usually not less than 1 to 2 kilograms were taken as a final sample. This sample served for the determination of the composition of the dry matter of the grain.

### HAY.

With the exception of the first two months (October and November, 1904), cut hay was used on account of the greater convenience of handling and greater accuracy of weighing out and sampling. For this purpose a suitable quantity was cut up at one time, thoroughly mixed, and stored. In most instances, and always in the respiration calorimeter experiments, samples were taken at the time when the hay was cut up. In some other cases samples were taken only as the hay was being fed out for the digestion trials.

Special care was taken to secure a uniform quality of hay in the several respiration calorimeter experiments of the same year. To this end, a stock more than sufficient for all the anticipated experiments was prepared at the outset. The method employed, which was substantially that followed also in the preparation of the stock used for the digestion and metabolism trials, was as follows:

The entire amount (1,000 to 2,000 kilograms) was cut in lengths of 4 to 5 centimeters. The mass of cut hay was thoroughly mixed with scoop shovels upon a tight floor and then spread out evenly in a mass 0.5 to 1 meter deep. A narrow ditch was then cut diagonally through the mass, the hay thus removed being set aside. A second ditch was then cut through at right angles to the first, and the material thus obtained also set aside. In all cases care was taken to secure the material down to the floor, including the finer particles. Each of the two large samples thus secured was thoroughly mixed, spread out on a tight floor, and subsampled by the method of quartering as already described for the grain, the process being repeated as often as necessary to secure a manageable sample. The sample was chopped rather fine in a meat chopper and resampled, 2 to 3 kilograms being finally taken to the laboratory for determination of the composition of the dry matter.

## WEIGHING OUT AND SAMPLING RATIONS.

The daily rations for each respiration calorimeter period or digestion trial were weighed out in advance for the whole time, the hay in cloth bags and the grain in closed receptacles, lard pails being usually employed. In this way it was insured that the animals should receive a uniform amount of dry matter each day. In weighing out the hay, the material was taken from the side of the pile, care being taken to secure all of it down to the floor. As each bag or other receptacle was filled a small portion was laid aside. As soon as the weighing out was finished the samples thus obtained were mixed and subsampled if necessary, the work being done as expeditiously as possible to prevent gain or loss of moisture and the final samples being taken to the laboratory in closed vessels. The results of each period were based upon the composition of the samples taken for that period, the results on the two general samples serving as a check.

The stalls are so arranged as to prevent scattering of feed by the animals. When small uneaten residues were left they were dried and fed back on the succeeding day. Larger residues, of which there were relatively few, were, of course, weighed, sampled, and analyzed.

## VISIBLE EXCRETA.

### FECES.

The feces were collected by means of the rubber duct mentioned in previous publications and originally described in Bulletin 42 of the Pennsylvania Experiment Station. The total excretion was weighed at the end of each 24 hours. Feces adhering to the duct were scraped or washed off at the close of the period and their dry matter determined, it being assumed that the composition of the latter was the same as that of the feces collected. Any material spilled was scraped up, but few such instances occurred.

A uniform aliquot sample of the fresh feces was set aside daily in a closed zinc can, a little carbon bisulphid being added as a preservative. At the close of the experiment the sample thus obtained was thoroughly mixed and constituted the sample for analysis. No daily analyses of the feces were made in these experiments.

### URINE.

The urine was collected by means of an ordinary urine funnel. The latter was rinsed out with water at the end of each 24 hours and the weight of the combined urine and wash water taken. No preservative was used in the receptacle, no indication of a necessity for it appearing.

A uniform aliquot sample of the urine was taken daily after thorough shaking, and these aliquots were mixed to form a composite sample which was preserved by the use of chloroform. With the exception of the respiration calorimeter experiments of 1905 and of the first 3 digestion and metabolism trials, a daily sample of the urine was also taken for determination of total nitrogen. Any urine spilled was taken up as completely as possible by means of sponges and distilled water, and a nitrogen determination made on the recovered material as a basis for a correction.

## ANALYTICAL METHODS.

### FEEDS AND FECES.

*Partial drying.*—The necessary preliminary drying was conducted by spreading the material out on trays and exposing it in a drying closet to a current of air which passed over a steam coil, the temperature of the closet being about 60° C. When thoroughly dry, the material was exposed to the air of the grinding room, properly protected, for two or three days. It was then weighed, an especially dry or damp day being avoided, and the material ground as rapidly as possible and preserved in sealed glass-stoppered bottles.

*Dry matter.*—In the experiments of 1905 the dry matter was determined by exposure to the temperature of boiling water, this being the method recommended by the Association of Official Agricultural Chemists.[1] Subsequent to that time, the dry matter was determined by drying at ordinary temperature in a high vacuum substantially by the method described by Benedict and Manning.[2]

*Ash.*—The figures reported for the ash refer to crude ash as determined by incineration at a low red heat.

*Crude fiber.*—The crude fiber was determined by the Weende method, following strictly the directions approved by the Association of Official Agricultural Chemists.[1]

*Ether extract.*—The ether extract was obtained by extracting the dry feed with anhydrous sulphuric ether, the extract being dried and weighed.

*Nitrogen.*—The total nitrogen was determined by the Kjeldahl method, using mercury as a catalyser. The total nitrogen in the sample of fresh feces was determined by König's method. Protein nitrogen was determined by precipitation with copper hydrate, substantially according to Stutzer, as recommended by the Association of Official Agricultural Chemists.[1]

Protein was computed from the protein nitrogen by multiplying by the following factors: For wheat bran, 5.7; corn meal, 6; linseed meal, 5.5; hay, 6.25; feces, 6.25. For the nonprotein, in the absence of any better data, the factor for asparagin, 4.7, was applied to the nonprotein nitrogen.

*Carbon and hydrogen.*—Carbon and hydrogen were determined by combustion with copper oxid with the addition of a little lead chromate in a current of pure air, finishing with oxygen. The water was absorbed in a Winkler spiral containing sulphuric acid, followed by a U tube containing pumice stone drenched with sulphuric acid and the carbon dioxid in a U tube containing soda lime followed by one containing pumice stone and sulphuric acid.

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[1] U. S. Dept. Agr., Bureau of Chemistry, Bulletin 107.

[2] Amer. Jour. Physiol., **13**, 309; **18**, 213.

*Energy.*—The energy content was determined by means of the Berthelot-Hempel bomb as modified by Atwater. The details of the methods employed have been fully described in previous bulletins.[1]

### URINE.

*Nitrogen.*—Nitrogen was determined in the fresh urine by the Kjeldahl method as described for feeding stuffs.

*Drying.*—It was of course necessary to dry the urine for the determination of carbon, hydrogen, and energy. In this drying some losses are unavoidable. For the determinations of carbon and hydrogen the urine was dried in a platinum boat at 60° C. in a current of air, this air current being purified by passing over sulphuric acid and soda lime. After passing over the substance the air current passed through standard acid, then through a sulphuric-acid drying bottle, followed by a U tube containing pumice stone and sulphuric acid, and finally through a soda-lime tube followed by a sulphuric-acid tube. The carbon of the carbon dioxid and the hydrogen of the ammonia given off, as thus determined, were added to the results obtained by the combustion of the dried residue.

*Carbon and hydrogen* were determined as in the feeds and feces.

*Energy.*—For the determination of energy six or seven samples of the urine, of about 10 grams each, were dried at ordinary temperature in a high vacuum in the platinum capsules used in the bomb calorimeter. Three of these samples served for the determination of energy and two as a check upon the amount of nitrogen lost during evaporation, the remaining samples constituting a reserve in case of accident. The residual solids in our experience have burned perfectly in the bomb calorimeter without the use of the celluloid block or any kindling material. To the energy thus determined was added the energy of the amount of urea corresponding to the nitrogen lost by the parallel samples.

### DETERMINATION OF RESPIRATORY PRODUCTS AND HEAT.

These determinations were made by means of the respiration calorimeter, which is a modification of the original form of the Atwater-Rosa apparatus.[2] It consists of a respiration apparatus, of the Pettenkofer type, which also serves as an animal calorimeter. The general construction of the apparatus has been described in previous publications. At the beginning of 1906 the large copper freezing cans previously used for condensing the larger share of the water vapor coming from the respiration chamber were removed and the outcoming air allowed to pass directly from the chamber to the meter pump, the results of the earlier experiments showing that with the very dry air supply used there was no danger of a condensation of moisture in the connections or the meter pump. The air samples taken automatically by the meter pump were allowed to bubble through concentrated sulphuric acid contained in a large gas washing bottle, passing from thence to the usual absorbing train. This arrangement proved to be fully as effective as the freezing cans, and at the same time simpler and more accurate. In addition to the samples taken by the meter pump, large aspirators of 800 liters capacity were also provided, by means of which an additional sample of the outgoing air was taken, especially as a control upon the moisture determinations.

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[1] Fries: U. S. Dept. of Agr., Bureau of Animal Industry, Bulletins 94 and 124.

[2] U. S. Dept. of Agr., Office of Experiment Stations, Bulletins 63 and 136.

### RESPIRATORY PRODUCTS.

No material changes were made in the methods of determining the respiratory products which were described in a previous publication.[1] In the experiments of 1907, in which, as already stated, the outgoing air was sampled both by means of the meter pump and by an aspirator, the average of the closely concordant results for carbon dioxid and water obtained by the two methods has been used. The methane in every case is computed from the carbon found in the combustible gases. The general methods of respiration experiments seem too familiar to require detailed description.

### HEAT.

The methods for determining the heat production of the animals were also largely the same as those described in the publication just cited, but some minor modifications were introduced and it seems appropriate to illustrate the methods by the record of one subperiod. For this purpose the first subperiod of Period I of the Experiments of 1907 upon steer A has been selected.

The heat given off by the animal leaves the calorimeter in part as the latent heat of evaporation of the water vapor produced. This portion is calculated from the amount of water vapor given off, using Smith's[2] factor of 0.587 calories per gram at 18° C. The remainder of the heat is taken up by the current of water passing through the pipes of the absorber system, the temperature of the ingoing and outcoming water being recorded every 4 minutes. The absorber pipes are partly protected by a shield, which can be raised or lowered by the operator so as to remove the heat from the chamber more or less rapidly, as may be necessary to maintain as nearly as possible a constant temperature. The walls of the respiration chamber are maintained adiabatic by heating or cooling the surrounding air spaces and the temperature of the ingoing air is maintained equal to that of the outcoming.

Table 220 is a transcript of one hour's record of the subperiod.

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[1] Bureau of Animal Industry, Bul. 51.

[2] Physical Review, 25, 170.

TABLE 220.—*Record of heat measurements.*

[Date Feb. 5, 1907. Experiment 207. Period I; subperiod 1. Animal A.]

| 1 | 2 |  | 3 | 4 | 5 | 6 | 7 |  | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Time 9 p. m. | Water thermometers. |  | Inside temperature by bridge. | Inner wall. | Middle wall. | Air current. | Water meters. |  | Lamps on air. | Sundries. |
|  | Observed. | Difference. |  |  |  |  | No. 1. | No. 2. |  |  |
|  | ° *C.* | ° *C.* | *m. m.* | − + | − + | − + |  |  |  |  |
| 00 | 11.38<br>5.62 | 5.76 | 287<br>287 | .5 | 1 | 1.5 |  |  |  | Steer moving head.<br>A−18. B−17.6. |
| 02 |  |  |  |  |  |  |  |  |  | Steer chewing cud. |
| 04 | 11.38<br>5.62 | 5.76 | 287<br>287 | .5 | 1 | 1 |  |  |  | Shield on balance. |
| 06 |  |  |  |  |  |  |  |  | 11½ |  |
| 08 | 11.44<br>5.62 | 5.82 | 290<br>288 | .5 | 1 | 1 |  |  |  |  |
| 10 |  |  |  |  |  |  |  |  |  |  |
| 12 | 11.44<br>5.61 | 5.83 | 290<br>288 | 1.5 | 4 | .5 | 91 L |  |  | 9°, 14′, 30″ Pointer 29. |
| 14 |  |  |  |  |  |  |  |  |  |  |
| 16 | 11.13<br>5.52 | 5.61 | 287<br>287 | 1.5 | 4 | 0 |  |  |  |  |
| 18 |  |  |  |  |  |  |  |  |  |  |
| 20 | 10.84<br>5.47 | 5.37 | 289<br>289 | .5 | 4 | .5 | 9,21 50 |  |  |  |
| 22 |  |  |  |  |  |  |  |  |  |  |
| 24 | 10.74<br>5.47 | 5.27 | 285<br>288 | 0.5 | 4 | 1.5 |  |  |  |  |
| 26 |  |  |  |  |  |  |  |  |  |  |
| 28 | 10.72<br>5.48 | 5.24 | 281<br>288 | .2 | 4 | 1 |  |  |  | Steer down on left side. |
| 30 |  |  |  |  |  |  |  | 11 L |  | Pointer 28, 9°, 30′, 30″. |
| 32 | 10.94<br>5.56 | 5.38 | 288<br>288 | .3 | 4 | 3 |  |  |  | Shield up 15. |
| 34 |  |  |  |  |  |  |  |  | 11 |  |
| 36 | 11.43<br>5.76 | 5.67 | 290<br>288 | 3.5 | 4.5 | 3.5 |  |  |  | A−18.1. B−17.6. |
| 38 |  |  |  |  |  |  |  |  |  | Shield down 10. |
| 40 | 11.55<br>5.82 | 5.73 | 290<br>288 | 3 | 4.5 | 3 |  |  |  |  |
| 42 |  |  |  |  |  |  |  |  |  |  |
| 44 | 11.62<br>5.84 | 5.78 | 290<br>289 | 2.5 | 4.5 | 2.5 |  |  |  | Shield down 6. |
| 46 |  |  |  |  |  |  |  |  |  |  |
| 48 | 11.97<br>5.85 | 6.12 | 289<br>288 | 3.5 | 3.5 | 2.5 |  |  |  |  |
| 50 |  |  |  |  |  |  |  |  |  |  |
| 52 | 12.15<br>5.86 | 6.29 | 288<br>286 | 4.5 | 2.5 | 2 |  |  |  |  |
| 54 |  |  |  |  |  |  |  |  |  |  |
| 56 | 12.18<br>5.86 | 6.32 | 283<br>285 | 2 | 3.5 | 2 |  |  |  |  |
| 58 |  |  |  |  |  |  |  |  |  |  |

In the foregoing table the double column 2 shows the readings of the water thermometers and the difference between the temperatures of the ingoing and outcoming water. Column 3 shows the temperature of the interior of the calorimeter as measured by copper resistance thermometers and a Wheatstone slide wire bridge, the readings being recorded in millimeters of the bridge scale, one millimeter equalling about 0.01° C. The upper number represents the temperature of the air and the lower the temperature of the walls. Column 4 shows the positive or negative deflections of the galvanometer, indicating the relative temperature of the inner copper and outer zinc sheets composing the walls of the respiration chamber proper. The figures express millimeters on the scale of the reflecting galvanometer, one millimeter being equivalent to about 0.01° C. The positive and negative deviations are made to compensate each other in the course of an experiment. Columns 5 and 6 show the corresponding results for the middle wall of the calorimeter and for the ventilating air current. Column 7 shows the time at which each of the two water meters filled and also the number of liters contained in it at the time the rate of flow of the water was changed, this rate being indicated in column 9 by the position of the pointer attached to the water valve. The letters A and B in column 9 refer to the readings of two mercurial thermometers suspended in the respiration chamber.

*Corrections.*—For each period of uniform water flow, the product of the amount of water passing through the heat absorbers into the average temperature difference equals the amount of heat brought out in the water current. Two corrections, however, are necessary.

First, the pipe composing our absorber system being of small diameter, there is a not inconsiderable pressure upon the bulbs of the thermometers, and this pressure varies with the rate of flow of the water. Since this pressure is greater upon the ingoing than upon the outcoming thermometer, the effect is to render the observed difference in temperature too small. A correction for this effect was worked out experimentally for the range of pressure used and is applied in the table.

Second, the friction of the water in the absorbers is itself the source of a small amount of heat, which has been computed from the difference in pressure at entrance and exit and the weight of the water passing through the absorbers.

For the specific heat of water between the temperatures observed, we have used the average of Dieterici and Barnes' figures,[1] which give the final result in mean calories, a mean calorie being defined as one-hundredth of the amount of heat required to raise the temperature of one kilogram of water from 0° to 100° C.

The first part of Table 221, on page 210, shows the results as thus computed for the whole of subperiod 1. To the heat thus measured must be added the latent heat of evaporation of the water vaporized as already explained. Furthermore, certain other small corrections are required, as follows:

First, corrections have to be made for the heat introduced into the apparatus or withdrawn from it in case the feed, drink, excreta, and vessels containing them were introduced or removed at a temperature different from that of the calorimeter. The net amount of these corrections is ordinarily small, but the single factors are sometimes not inconsiderable. This is especially the case with the feces, where considerable difficulty is sometimes experienced in determining satisfactorily the true average temperature of the mass.

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[1] Ann. Phys., 16, 616.

Second, the temperature of the walls of the chamber is subject to slight fluctuations. This temperature is expressed, as already noted, in millimeters of the scale of the slide wire bridge. It has been experimentally determined that 1 millimeter difference in temperature on this scale is equivalent to a capacity correction of 2 calories. The temperature of the contained air also varies slightly, but the error thus introduced is so small as to be negligible.

Third, a correction for so-called lag is also necessary. The water temperatures which are compared are read simultaneously at the inlet and outlet of the absorber system. A certain time is required, however, for the water to pass from one of these points to the other, and, if the temperature of the ingoing water is changing, the ingoing thermometer is affected before the outgoing one. Assuming the rate of emission of heat in the calorimeter and the rate of flow of the water through the absorbers to remain constant, let the lines AA and BB in figure 17 represent the temperatures of the ingoing and outcoming water, respectively, and let the distances between the vertical lines represent the time required for the water to pass from the inlet to the outlet of the absorber system. At the instant *4* the temperature of the ingoing water begins to rise at a uniform rate and continues to do so until the instant *15*, when it again becomes constant. The temperature of the outgoing water will not be affected, however, until the warmer water has passed through the absorbers and will therefore lag behind that of the ingoing water. Its rise of temperature, disregarding possible convection currents in the flowing water and heat conduction by the metal of the absorbers, will begin at the instant *5* and continue until *16* and from the 5th to the 15th instant, inclusive, the apparent temperature difference will be too small by the amount by which the temperature of the ingoing water rises in one interval. If the two thermometers are read simultaneously at the end of each interval, the correction for lag will obviously equal the amount of water contained in the absorber system (in our apparatus 3 kilograms) multiplied by the rise in temperature of the ingoing water during one interval. With a falling temperature of the ingoing

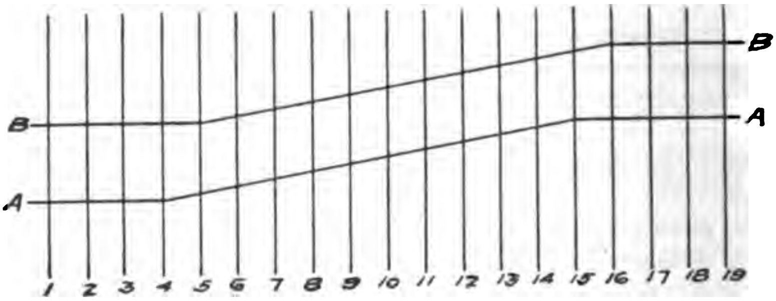

FIG. 17.—Temperature of ingoing and outcoming water in calorimeter.

water the effect would be reversed, the apparent temperature difference being too great. Plainly, then, we may use the net rise or fall of temperature of the ingoing water during the whole of an experiment or period as the basis of the correction without regard to intermediate fluctuations. The error due to lag is superadded to any effects of changes in the temperature of the outgoing water due to other causes, such as variations in the rate of heat emission in the calorimeter or in the rate of flow of water through the absorbers. In practice, the temperatures are seldom read at intervals corresponding exactly to the rate of flow of the water, and in this way complications are introduced into the exact calculation of the lag correction, but in view of the small total amount of heat involved the correction computed in the manner indicated has been regarded as a sufficiently close approximation.

Fourth, the temperature of the absorber system may differ at the beginning and end of a subperiod, thus requiring a capacity correction. Our absorber system, including the contained water, is equivalent in heat capacity to 6 kilograms of water. If we suppose the temperature of the ingoing water to remain constant the mean temperature of the system may be assumed to be equal to the average of the temperature of the entering and outgoing water, and this difference multiplied by the water equivalent of the system gives the correction to be applied.

If, however, the temperature of the ingoing water varies, the case is different. For example, in the case considered in the previous paragraph, the temperature of the absorber system rises, but this is caused by a storing up in it of heat supplied by the water current and not by heat generated in the calorimeter, and therefore there is no capacity correction. Similarly, in the reverse case, while the temperature of the absorber system falls this is virtually due to the abstraction from it of heat previously imparted to it by the water current, and again there is no capacity correction. Only when the temperature at the inlet and exit vary by different amounts is there a capacity correction equal to the water equivalent of the absorber system multiplied by one-half the difference between the average temperature differences at the beginning and end of the period under consideration. For example:

| | At beginning of period. | At end of period. |
|---|---|---|
| Temperature at outlet | 10° | 13° |
| Temperature at inlet | 4° | 5° |
| | 6° | 8° |

$$\text{Correction } \frac{8^\circ-6^\circ}{2}\times 6 \text{ kilos}=6 \text{ calories.}$$

All the foregoing corrections are included in the second part of Table 221.

TABLE 221.—*Heat emission.*

[Date, February 5 and 6, 1907. Experiment, 207. Period, I; subperiod, 1. Animal, A.]

| Period. | Minutes. | Relative rate of flow—pointer at— | Average temperature of water current. | | | | | Total water. | Average specific heat of water. | Mean calories. | Heat produced in absorbers. | | Total heat - mean calories. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ingoing. | Out-coming. | Differ-ence. | Correc-tion for pressure. | Corrected differ-ence. | | | | Differ-ence of pressure. | Equiv-alent heat. | |
| | | | ° *C.* | ° *C.* | ° *C.* | ° *C.*+ | ° *C.* | *Liters.* | | | *Cm.* | *Cal.* | |
| 6.00 p. m. to 7.07 p. m. | 67 | 28 | 5.8539 | 11.7600 | 5.9061 | 0.0006 | 5.9067 | 60 | 1.0036 | 355.68 | 0.30 | 0.01 | 355.67 |
| 7.07 p. m. to 9.14 p. m. | 127 | 28½ | 5.6644 | 11.3785 | 5.7141 | .0007 | 5.7148 | 131 | 1.0037 | 751.41 | .35 | .01 | 751.40 |
| 9.14 p. m. to 9.30 p. m. | 16 | 29 | 5.4975 | 10.8125 | 5.3150 | .0008 | 5.3158 | 20 | 1.0039 | 106.73 | .40 | .00 | 106.73 |
| 9.30 p. m. to 12.47 a. m. | 197 | 28 | 5.7988 | 11.8872 | 6.0884 | .0006 | 6.0890 | 157 | 1.0036 | 959.41 | .30 | .01 | 959.40 |
| 12.47 a. m. to 1.25 a. m. | 38 | 29 | 5.4770 | 11.1360 | 5.6590 | .0008 | 5.6598 | 42½ | 1.0038 | 241.46 | .40 | .01 | 241.45 |
| 1.25 a. m. to 2.15 a. m. | 50 | 29½ | 5.3108 | 10.0883 | 4.7775 | .0009 | 4.7784 | 69½ | 1.0042 | 333.49 | .45 | .01 | 333.48 |
| 2.15 a. m. to 2.30 a. m. | 15 | 29½ | 5.2967 | 9.5367 | 4.2400 | .0009 | 4.2409 | 20 | 1.0040 | 85.16 | .45 | .00 | 85.16 |
| 2.30 a. m. to 3.10 a. m. | 40 | 29 | 5.3680 | 9.7450 | 4.3770 | .0008 | 4.3778 | 49 | 1.0042 | 215.41 | .40 | .01 | 215.40 |
| 3.10 a. m. to 4.21 a. m. | 71 | 28½ | 5.4706 | 10.3311 | 4.8605 | .0007 | 4.8612 | 71 | 1.0040 | 346.53 | .35 | .01 | 346.52 |
| 4.21 a. m. to 6.00 a. m. | 99 | 29½ | 5.1792 | 9.7009 | 4.5217 | .0009 | 4.5226 | 133 | 1.0043 | 604.09 | .45 | .02 | 604.07 |
| Total heat from absorbers | | | | | | | | | | | | | 3,999.28 |
| Latent heat of water vapor at 18° C., 1,801.91 grams×0.587= | | | | | | | | | | | | | 1,057.72 |
| Sum | | | | | | | | | | | | | 5,057.00 |

| Corrections. | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Temperature, °C. | Weight. | Specific heat.[1] | Temperature difference. | +Calories. | −Calories. | |
| Temperature of chamber | 17.9 | | | | | | |
| Feed introduced: | | | | | | | |
| Dry matter— | | | | | | | |
| Hay | 18.3 | 1.468 kilos | ×0.4000 | ×+0.4 °C | | 0.23 | |
| Grain | 17.2 | 1.001 kilos | ×0.4000 | ×−0.7 °C.= | 0.28 | | |
| Water— | | | | | | | |
| Hay | 18.3 | .090 kilo | ×1.0000 | ×0.4 °C | | .04 | |
| Grain | 17.2 | .165 kilo | ×1.0000 | ×−0.7 °C.= | .12 | | |
| Feed box introduced | 18.3 | 12.955 kilos | ×0.1138 | ×+0.4 °C.= | | .59 | |
| Urine box introduced | 18.0 | 3.045 kilos | ×0.0930 | ×+0.1 °C.= | | .03 | |
| Feces box introduced | 18.0 | 8.715 kilos | ×0.1138 | ×+0.1 °C.= | | .10 | |
| Changes in temperature of absorber system | | 6 kilos | ×1.0000 | ×−0.745 °C.= | | 4.47 | |
| Changes in temperature of wall | | 2 calories | | ×+3 mm.= | 6.00 | | |
| Changes in temperature of ingoing water (lag) | | 3 kilos | | ×−0.72 °C.= | | 2.16 | |
| Total | | | | | 6.40 | 7.62 | |
| Algebraic sum | | | | | | | −1.22 |
| Total heat emission corrected | | | | | | | 5,055.78 |

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[1] This column contains the specific heats that are used in making corrections for substances introduced into or removed from the calorimeter.

*Rate of heat emission.*—The rate of heat emission per minute, which is represented graphically in figure 16 (see p. 118), is computed as follows:

First, the average rate of flow of water through the heat absorbers between the times when the rate is purposely changed by the operator is computed in the manner illustrated in Table 222. The results for the short periods serve as a check upon the uniformity of the rate of flow.

TABLE 222.—*Record of water flow from heat absorbers.*

[Date, Feb. 5, 1907. Experiment 207. Period I, subperiod 1. Animal A.]

| Sundries. | Water-flow record. | | | | Average flow in liters per minute. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Valve pointer. | Time. | Meter. | | Short periods. | | | Longer periods. | | |
| | | *Hr. min.*<br>P. M. | *No.* | *Liters.* | *Min.* | *Liters.* | *Flow.* | *Min.* | *Liters.* | *Flow.* |
| | 28½ | 4 55¾ | II | 71½ | ...... | ...... | ...... | ...... | ...... | ...... |
| | | 5 26¾ | II | 100 | 31 | 28½ | 0.9194 | ...... | ...... | ...... |
| Began...... | ...... | 6 00 | I | 29½ | 33¼ | 29½ | .8872 | 64¼ | 58 | 0.9027 |
| Steer up...... | 28 | 7 7½ | II | 60 | 67½ | 60 | .8889 | 67½ | 60 | .8889 |
| | 28½ | 7 45½ | II | 100 | 38 | 40 | 1.0526 | ...... | ...... | ...... |
| | | 9 14½ | I | 91 | 89 | 91 | 1.0225 | 127 | 131 | 1.0315 |
| No. 1 failed to ring off...... | 29 | 9 21¾ | I | 100 | 7¼ | 9 | 1.2414 | ...... | ...... | ...... |
| Steer down 9° 29′...... | ...... | 9 30½ | II | 11 | 8¾ | 11 | 1.2571 | 16 | 20 | 1.2500 |
| | 28 | 11 21½ | II | 100 | 111 | 89 | .8018 | ...... | ...... | ...... |
| Steer up 12° 46′ a. m...... | ...... | A. M.<br>12 47 | I | 68 | 85½ | 68 | .7953 | 196½ | 157 | .7990 |
| No. 1 failed to ring off when full...... | 29 | [1] 1 15.68 | I | 100 | 28.68 | 32 | [1] 1.1159 | ...... | ...... | ...... |
| | | 1 21½ | II | 6½ | 5.82 | 6½ | [1] 1.1159 | ...... | ...... | ...... |
| | | 1 25½ | II | 10½ | 4 | 4 | 1.0000 | 38.50 | 42.5 | [1] 1.1039 |
| Steer down 2° 15′...... | 29½ | 2 15 | II | 80 | 49½ | 69½ | 1.4040 | ...... | ...... | ...... |
| | | 2 30 | II | 100 | 15 | 20 | 1.3333 | 64½ | 89½ | 1.3876 |
| | 29 | 3 10 | I | 49 | 40 | 49 | 1.2250 | 40 | 49 | 1.2250 |
| No. 1 failed to ring off...... | 28½ | 4 [2] 1.36 | I | 100 | 51.36 | 51 | [2] .9930 | ...... | ...... | ...... |
| | | 4 21½ | II | 20 | 20.14 | 20 | [2] .9930 | 71.50 | 71 | .9930 |
| | 29½ | 5 20 | II | 100 | 58½ | 80 | 1.3675 | ...... | ...... | ...... |
| End...... | ...... | 6 00 | I | 53 | 38½ | 53 | 1.3766 | 97 | 133 | 1.3711 |
| Clock set ahead 1½ minutes (subtract 1½ minutes)...... | ...... | ...... | ...... | ...... | 1½ | ...... | ...... | 1½ | ...... | ...... |
| | | | | | 720.0<br>718.5 | ......<br>753 | ......<br>...... | 720<br>718.5 | ......<br>753 | ......<br>...... |

[1] Time and flow calculated from 12.47 to 1.21½.
[2] Time and flow calculated from 3.10 to 4.21½.

Second, the average temperature differences for overlapping periods of 12 minutes each are computed and entered, as shown in Table 223, opposite the time corresponding to the middle of the 12-minute period. The following example, taken from another experiment, serves to illustrate the method of computing these temperature differences.

| Time. | Recorded temperature differences. | Average temperature differences. |
|---|---|---|
| 9.20 | 3.71 | |
| 9.24 | 3.75 | 3.75 |
| 9.28 | 3.80 | 3.79 |
| 9.32 | 3.83 | 3.82 |
| 9.36 | 3.83 | |

At transition points between two rates of flow, the last two recorded temperature differences under the old rate of flow are averaged and this average entered opposite the time corresponding to the last temperature difference. The temperature differences recorded under the new rate of flow are treated similarly, as in the following example.

| Time. | Recorded temperature differences. | Average temperature differences. |
|---|---|---|
| 1.36 | 4.11 | |
| 1.40 | 4.11 | 4.12 |
| 1.44 | 4.14 | 4.13 |
| Flow changed. | | |
| 1.48 | 1.95 | |
| 1.52 | 1.74 | 1.85 |
| 1.50 | 1.76 | 1.82 |

The products of these average temperature differences into the average rate of water flow per minute as computed in Table 222 are regarded as expressing the average rate of heat emission at that time. Of course this includes only the heat imparted to the water in the absorbers by radiation, conduction, and convection from the animal and does not cover the heat given off as latent heat of water vapor.

TABLE 223.—*Average heat radiation per minute.*

[Date, Feb. 5, 1907. Experiment 207. Period I, subperiod 1. Animal A.]

| Time. | 6 p. m. to 9 p. m. | | | 9 p. m. to 12 a. m. | | | 12 a. m. to 3 a. m. | | | 3 a. m. to 6 a. m. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average temperature difference. | Flow (liters per minute). | Heat (calories per minute). | Average temperature difference. | Flow (liters per minute). | Heat (calories per minute). | Average temperature difference. | Flow (liters per minute). | Heat (calories per minute). | Average temperature difference. | Flow (liters per minute). | Heat (calories per minute). |
| | °C. | | | °C. | | | °C. | | | °C. | | |
| 00..... | 5.79 | 0.8889 | 5.1467 | 5.76 | ........ | 5.9414 | 6.07 | ........ | 4.8499 | ........ | ........ | ........ |
| 04..... | 5.81 | ........ | 5.1645 | 5.78 | ........ | 5.9621 | 6.07 | ........ | 4.8499 | 4.17 | ........ | 5.1083 |
| 08..... | 5.78 | ........ | 5.1378 | 5.80 | ........ | 5.9827 | 6.08 | ........ | 4.8579 | 4.28 | ........ | 5.2430 |
| 12..... | 5.73 | ........ | 5.0934 | 5.72 | ........ | 5.9002 | 6.09 | ........ | 4.8659 | 4.28 | ........ | 5.2430 |
| 16..... | 5.72 | ........ | 5.0845 | 5.72 | ........ | 5.9002 | 6.10 | ........ | 4.8739 | 4.70 | 0.9930 | 4.6671 |
| 20..... | 5.75 | ........ | 5.1112 | 5.32 | 1.2500 | 6.6500 | 6.09 | ........ | 4.8659 | 4.70 | ........ | 4.6671 |
| 24..... | 5.78 | ........ | 5.1378 | 5.32 | ........ | 6.6500 | 6.07 | ........ | 4.8499 | 4.78 | ........ | 4.7465 |
| 28..... | 5.80 | ........ | 5.1556 | 5.31 | ........ | 6.6375 | 6.06 | ........ | 4.8419 | 4.79 | ........ | 4.7565 |
| 32..... | 5.82 | ........ | 5.1734 | 5.31 | ........ | 6.6375 | 6.07 | ........ | 4.8499 | 4.81 | ........ | 4.7763 |
| 36..... | 5.87 | ........ | 5.2178 | 5.70 | .7990 | 4.5543 | 6.08 | ........ | 4.8579 | 4.81 | ........ | 4.7763 |
| 40..... | 5.92 | ........ | 5.2623 | 5.70 | ........ | 4.5543 | 6.08 | ........ | 4.8579 | 4.81 | ........ | 4.7763 |
| 44..... | 5.97 | ........ | 5.3067 | 5.84 | ........ | 4.6662 | 6.09 | ........ | 4.8659 | 4.81 | ........ | 4.7763 |
| 48..... | 6.01 | ........ | 5.3423 | 6.06 | ........ | 4.8419 | 6.09 | ........ | 4.8659 | 4.81 | ........ | 4.7763 |
| 52..... | 6.06 | ........ | 5.3867 | 6.24 | ........ | 4.9858 | 5.81 | 1.1040 | 6.4142 | 4.82 | ........ | 4.7863 |
| 56..... | 6.10 | ........ | 5.4223 | 6.32 | ........ | 5.0497 | 5.81 | ........ | 6.4142 | 4.83 | ........ | 4.7962 |
| 00..... | 6.14 | ........ | 5.4578 | 6.33 | ........ | 5.0577 | 5.79 | ........ | 6.3922 | 4.84 | ........ | 4.8061 |
| 04..... | 6.13 | ........ | 5.4490 | 6.34 | ........ | 5.0657 | 5.73 | ........ | 6.3259 | 4.84 | ........ | 4.8061 |
| 08..... | 6.13 | ........ | 5.4490 | 6.35 | ........ | 5.0737 | 5.68 | ........ | 6.2707 | 4.82 | ........ | 4.7863 |
| 12..... | 5.81 | 1.0315 | 5.9930 | 6.36 | ........ | 5.0816 | 5.67 | ........ | 6.2597 | 4.82 | ........ | 4.7863 |
| 16..... | 5.81 | ........ | 5.9930 | 6.33 | ........ | 5.0577 | 5.66 | ........ | 6.2486 | 5.01 | ........ | 4.9749 |
| 20..... | 5.71 | ........ | 5.8899 | 6.25 | ........ | 4.9938 | 5.65 | ........ | 6.2376 | 5.33 | ........ | 5.2927 |
| 24..... | 5.68 | ........ | 5.8589 | 6.17 | ........ | 4.9298 | 5.45 | ........ | 6.0168 | 5.33 | ........ | 5.2927 |
| 28..... | 5.66 | ........ | 5.8383 | 6.12 | ........ | 4.8899 | 5.45 | ........ | 6.0168 | 4.90 | 1.3711 | 6.7184 |
| 32..... | 5.65 | ........ | 5.8280 | 6.12 | ........ | 4.8899 | 4.90 | 1.3876 | 6.7992 | 4.90 | ........ | 6.7184 |
| 36..... | 5.64 | ........ | 5.8177 | 6.12 | ........ | 4.8899 | 4.90 | ........ | 6.7992 | 4.77 | ........ | 6.5401 |
| 40..... | 5.65 | ........ | 5.8280 | 6.10 | ........ | 4.8739 | 4.84 | ........ | 6.7160 | 4.68 | ........ | 6.4167 |
| 44..... | 5.64 | ........ | 5.8280 | 6.07 | ........ | 4.8499 | 4.82 | ........ | 6.6882 | 4.57 | ........ | 6.2659 |
| 48..... | 5.67 | ........ | 5.8486 | 6.04 | ........ | 4.8260 | 4.78 | ........ | 6.6327 | 4.47 | ........ | 6.1288 |
| 52..... | 5.68 | ........ | 5.8589 | 6.02 | ........ | 4.8100 | 4.77 | ........ | 6.6189 | 4.43 | ........ | 6.0740 |
| 56..... | 5.68 | ........ | 5.8589 | 6.02 | ........ | 4.8100 | 4.76 | ........ | 6.6050 | 4.42 | ........ | 6.0603 |
| 00..... | 5.66 | ........ | 5.8383 | 6.02 | ........ | 4.8100 | 4.75 | ........ | 6.5911 | 4.41 | ........ | 6.0466 |
| 04..... | 5.66 | ........ | 5.8383 | 6.02 | ........ | 4.8100 | 4.73 | ........ | 6.5633 | 4.41 | ........ | 6.0466 |
| 08..... | 5.66 | ........ | 5.8383 | 6.01 | ........ | 4.8020 | 4.72 | ........ | 6.5495 | 4.42 | ........ | 6.0603 |
| 12..... | 5.67 | ........ | 5.8486 | 6.02 | ........ | 4.8100 | 4.70 | ........ | 6.5217 | 4.43 | ........ | 6.0740 |
| 16..... | 5.68 | ........ | 5.8589 | 6.03 | ........ | 4.8180 | 4.55 | ........ | 6.3136 | 4.45 | ........ | 6.1014 |
| 20..... | 5.69 | ........ | 5.8692 | 6.05 | ........ | 4.8340 | 4.38 | ........ | 6.0777 | 4.46 | ........ | 6.1151 |
| 24..... | 5.71 | ........ | 5.8899 | 6.05 | ........ | 4.8340 | 4.24 | ........ | 5.8834 | 4.52 | ........ | 6.1974 |
| 28..... | 5.74 | ........ | 5.9208 | 6.06 | ........ | 4.8419 | 4.35 | ........ | 6.0361 | 4.57 | ........ | 6.2659 |
| 32..... | 5.78 | ........ | 5.9621 | 6.06 | ........ | 4.8419 | 4.35 | ........ | 6.0361 | 4.59 | ........ | 6.2933 |
| 36..... | 5.79 | ........ | 5.9724 | 6.06 | ........ | 4.8419 | 4.59 | 1.2250 | 5.6228 | 4.59 | ........ | 6.2933 |
| 40..... | 5.78 | ........ | 5.9621 | 6.05 | ........ | 4.8340 | 4.59 | ........ | 5.6228 | 4.54 | ........ | 6.2248 |
| 44..... | 5.76 | ........ | 5.9414 | 6.05 | ........ | 4.8340 | 4.42 | ........ | 5.4145 | 4.47 | ........ | 6.1288 |
| 48..... | 5.76 | ........ | 5.9414 | 6.04 | ........ | 4.8260 | 4.36 | ........ | 5.3410 | 4.38 | ........ | 6.0054 |
| 52..... | 5.76 | ........ | 5.9414 | 6.05 | ........ | 4.8340 | 4.33 | ........ | 5.3043 | 4.32 | ........ | 5.9232 |
| 56..... | 5.76 | ........ | 5.9414 | ........ | ........ | 4.8340 | 4.33 | ........ | 5.3043 | 4.33 | ........ | 5.9369 |
| 00..... | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 4.41 | ........ | 6.0466 |

From selected portions of the curve, as indicated on figure 16, the average heat emission per minute standing and lying is computed in the manner shown in Tables 224 and 225. The capacity corrections for walls and absorber system and the lag correction are computed for each section separately.

TABLE 224.—*Heat emission—Standing.*

[Date Feb. 5 and 6, 1907. Experiment 207. Period I A. Animal A.]

| Periods. | Minutes. | Pointer. | Rate of flow per minute. | Average temperature of water current. | | | | | Total water. | Average specific heat of water. | Mean calories. | Capacity corrections. | | | Heat produced in absorbers. | | Total heat—mean calories. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Ingoing. | Outcoming. | Difference. | Plus correction for pressure on thermometers. | Corrected difference. | | | | Lag. | Absorber system. | Walls. | Difference in pressure. | Equivalent heat. | |
| | | | *Liters.* | *°C.* | *°C.* | *°C.* | *°C.* | *°C.* | *Liters.* | | | *Cal.* | *Cal.* | *Cal.* | *Cm.* | *Cal.* | |
| 6.00 p. m. to 7.00 p. m.... | 60 | 28 | 0.8889 | 5.8556 | 11.7338 | 5.8782 | 0.0006 | 5.8788 | 53.33 | 1.00201 | 314.15 | +0.03 | +1.05 | +28 | 0.30 | 0.01 | 343.22 |
| 7.20 p. m. to 9.08 p. m.... | 108 | 28.5 | 1.0315 | 5.6668 | 11.3739 | 5.7071 | .0007 | 5.7078 | 111.40 | 1.00216 | 637.22 | − .27 | + .39 | + 4 | .35 | .01 | 641.33 |
| 1.00 a. m. to 1.20 a. m.... | 20 | 29 | 1.1039 | 5.4800 | 11.1600 | 5.6800 | .0008 | 5.6808 | 22.08 | 1.00226 | 125.72 | − .03 | − .33 | 0 | .40 | .00 | 125.36 |
| 1.40 a. m. to 2.12 a. m.... | 32 | 29.5 | 1.3876 | 5.3089 | 10.0756 | 4.7667 | .0009 | 4.7676 | 44.40 | 1.00256 | 212.22 | − .03 | − .33 | − 2 | .45 | .00 | 209.86 |
| 4.36 a. m. to 6.00 a. m.... | 84 | 29.5 | 1.3711 | 5.1719 | 9.6532 | 4.4813 | .0009 | 4.4822 | 115.17 | 1.00272 | 517.62 | − .27 | −1.41 | + 4 | .45 | .02 | 519.92 |
| 6.00 a. m. to 7.40 a. m.... | 100 | 29.5 | 1.2975 | 5.0938 | 9.4981 | 4.4043 | .0009 | 4.4052 | 129.75 | 1.00278 | 573.16 | − .21 | − .45 | − 6 | .45 | .02 | 566.48 |
| 9.16 a. m. to 9.40 a. m.... | 24 | 30 | 1.4589 | 4.9100 | 9.2214 | 4.3114 | .0010 | 4.3124 | 35.01 | 1.00292 | 151.42 | − .06 | − .42 | −12 | .50 | .01 | 138.93 |
| 12.24 p. m. to 12.56 p. m.... | 32 | 30 | 1.4147 | 4.8311 | 9.4967 | 4.6656 | .0010 | 4.6666 | 45.27 | 1.00286 | 211.86 | − .21 | − .78 | − 8 | .50 | .01 | 202.86 |
| 3.04 p. m. to 3.44 p. m.... | 40 | 30 | 1.4979 | 4.8900 | 9.2036 | 4.3136 | .0010 | 4.3146 | 59.92 | 1.00292 | 259.29 | − .06 | − .33 | −10 | .50 | .01 | 248.89 |
| 4.40 p. m. to 6.00 p. m.... | 80 | 30 | 1.5556 | 4.8652 | 8.7352 | 3.8700 | .0010 | 3.8710 | 124.45 | 1.00306 | 483.22 | − .06 | −1.41 | − 8 | .50 | .02 | 473.73 |
| 6.00 p. m. to 8.24 p. m.... | 144 | 30 | 1.5585 | 4.9184 | 8.8592 | 3.9408 | .0010 | 3.9418 | 224.42 | 1.00302 | 887.29 | + .12 | +1.86 | +18 | .50 | .04 | 907.23 |
| 8.52 p. m. to 9.16 p. m.... | 24 | 30 | 1.5484 | 4.9371 | 9.1486 | 4.2115 | .0010 | 4.2125 | 37.16 | 1.00291 | 156.99 | + .06 | + .24 | + 6 | .50 | .01 | 163.28 |
| 4.28 a. m. to 6.00 a. m.... | 92 | 30 | 1.5142 | 4.9729 | 9.1396 | 4.1667 | .0010 | 4.1677 | 139.31 | 1.00291 | 582.29 | − .24 | −1.44 | 0 | .50 | .02 | 580.59 |
| 6.00 a. m. to 7.52 a. m.... | 112 | 30 | 1.4777 | 4.9241 | 8.9076 | 3.9835 | .0010 | 3.9845 | 165.50 | 1.00300 | 661.42 | − .06 | − .06 | − 4 | .50 | .03 | 657.27 |
| 10.16 a. m. to 10.52 a. m.... | 36 | 30 | 1.3843 | 4.9690 | 9.7590 | 4.7900 | .0010 | 4.7910 | 49.83 | 1.00276 | 239.39 | − .03 | − .15 | −16 | .50 | .01 | 223.20 |
| 12.56 p. m. to 1.20 p. m.... | 24 | 30 | 1.4663 | 5.4729 | 9.9814 | 4.5085 | .0010 | 4.5095 | 35.19 | 1.00254 | 159.09 | + .15 | − .09 | + 6 | .50 | .01 | 165.14 |
| 3.52 p. m. to 6.00 p. m.... | 128 | 30 | 1.5200 | 5.8655 | 9.9427 | 4.0772 | .0010 | 4.0782 | 194.56 | 1.00242 | 795.38 | + .06 | −1.38 | − 6 | .50 | .03 | 788.03 |
| | 1,140 | | | | | | | | | | | | | | | | 6,955.32 |
| Corrections for feed, feed boxes, dung, and urine introduced and removed. | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | +76.12 |
| | | | | | | | | | | | | | | | | | 7,031.44 |
| Average heat emission (calories per minute)........ | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 6.1679 |

TABLE 225.—*Heat emission—Lying.*

[Date Feb. 5 and 6, 1907. Experiment 207. Period I A. Animal A.]

| Periods. | Minutes. | Pointer. | Rate of flow per minute. | Average temperature of water current. | | | | | Total water. | Average specific heat of water. | Mean calories. | Capacity corrections. | | | Heat produced in absorbers. | | Total heat—mean calories. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Ingoing. | Outcoming. | Difference. | Plus correction for pressure on thermometers. | Corrected difference. | | | | Lag. | Absorber system. | Walls. | Difference in pressure. | Equivalent heat. | |
| | | | *Liters.* | °*C.* | °*C.* | °*C.* | °*C.* | °*C.* | *Liters.* | | | *Cal.* | *Cal.* | *Cal.* | *Cm.* | *Cal.* | |
| 9.48 p. m. to 12.40 a. m.... | 172 | 28 | 0.7990 | 5.8005 | 11.9136 | 6.1131 | 0.0006 | 6.1137 | 137.43 | 1.00200 | 841.89 | −0.21 | −0.12 | −28 | 0.30 | 0.01 | 813.55 |
| 3.24 a. m. to 4.12 a. m.... | 48 | 28.5 | .9930 | 5.4808 | 10.2962 | 4.8154 | .0007 | 4.8161 | 47.66 | 1.00245 | 230.10 | − .09 | + .09 | − 4 | .35 | .01 | 226.09 |
| 8.04 a. m. to 8.56 a. m.... | 52 | 28 | .7362 | 5.5929 | 11.5857 | 5.9928 | .0006 | 5.9934 | 38.28 | 1.00212 | 229.91 | − .42 | + .66 | −18 | .30 | .00 | 212.15 |
| 10.00 a. m. to 12.04 p. m.... | 124 | 28 | .6891 | 5.3384 | 11.9294 | 6.5910 | .0006 | 6.5916 | 85.45 | 1.00213 | 564.45 | − .12 | +1.83 | + 4 | .30 | .01 | 570.15 |
| 1.24 p. m. to 2.44 p. m.... | 80 | 28 | .7033 | 5.3662 | 11.5786 | 6.2124 | .0006 | 6.2130 | 56.26 | 1.00220 | 350.31 | + .30 | + .99 | + 8 | .30 | .01 | 359.59 |
| 4.08 p. m. to 4.20 p. m.... | 12 | 28 | .8333 | 5.2525 | 10.6875 | 5.4350 | .0006 | 5.4356 | 10.00 | 1.00243 | 54.49 | + .06 | + .06 | − 4 | .30 | .00 | 50.61 |
| 9.40 p. m. to 10.32 p. m.... | 52 | 28 | .7987 | 5.3843 | 11.6729 | 6.2886 | .0006 | 6.2892 | 41.53 | 1.00218 | 261.76 | 0 | + .30 | −10 | .30 | .00 | 252.06 |
| 11.20 p. m. to 1.16 a. m.... | 116 | 28 | .8459 | 5.3530 | 11.4613 | 6.1083 | .0006 | 6.1089 | 98.12 | 1.00224 | 600.75 | + .03 | − .54 | −14 | .30 | .01 | 586.23 |
| 1.56 a. m. to 4.08 a. m.... | 132 | 28 | .8664 | 5.3626 | 11.2629 | 5.9003 | .0006 | 5.9009 | 114.36 | 1.00228 | 676.37 | − .09 | − .78 | −16 | .30 | .01 | 659.49 |
| 8.16 a. m. to 9.56 a. m.... | 100 | 28 | .7002 | 5.3750 | 11.6631 | 6.2881 | .0006 | 6.2887 | 70.02 | 1.00218 | 441.29 | + .15 | +2.10 | +26 | .30 | .01 | 469.53 |
| 11.16 a. m. to 12.36 p. m.... | 80 | 28 | .7150 | 5.5286 | 12.0200 | 6.4914 | .0006 | 6.4920 | 57.20 | 1.00205 | 372.10 | +1.23 | − .21 | −18 | .30 | .01 | 355.11 |
| 1.44 p. m. to 3.32 p. m.... | 108 | 28 | .7249 | 6.1961 | 12.6114 | 6.4153 | .0006 | 6.4159 | 78.29 | 1.00173 | 503.17 | − .30 | + .75 | − 4 | .30 | .01 | 499.61 |
| | 1,076 | | | | | | | | | | | | | | | | 5,054.17 |
| Average heat emission (calories per minute)........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 4.6972 |

### CHECK TESTS WITH THE RESPIRATION CALORIMETER.

The accuracy of a complicated apparatus like the respiration calorimeter can, of course, be satisfactorily determined only by actual test. Our check tests have been made by burning known amounts of ethyl alcohol in the respiration chamber and measuring the amounts of carbon dioxid, water, and heat evolved precisely as in an animal experiment.

So-called absolute alcohol, purchased from Eimer and Amend, was diluted to a strength of about 90 per cent with distilled water and the amount of anhydrous alcohol contained in the mixture computed from the specific gravity as determined by a 50 c. c. Squibb's pyknometer at 15.6° C. The alcohol was burned in an argand lamp, into which it was fed from outside the chamber by a device which maintained a constant level in the lamp. This lamp was burned for at least two preliminary hours, during which regular ventilation of the chamber was maintained and the heat removed by the water current as fast as produced. Only when everything was in equilibrium was the actual experiment begun.

Except in the tests of January 12 and May 8, 1906, in which Atwater and Benedict's average of 7.067 calories per gram was used, the heat of combustion of the alcohol used was determined by means of the bomb calorimeter, and ranged from 7.131 to 7.184 calories per gram of anhydrous alcohol. These figures are materially higher than the average used by Atwater and Benedict.

Up to the end of the year 1908–9 there had been made in all 18 alcohol check experiments, excluding those made on January 7, 1907, and April 29, 1908, which seemed clearly erroneous.[1]

Table 226 contains the results of these 18 check tests, divided into two groups, the first including those made with the original form of apparatus and the second those made with the apparatus as described on page 204, viz, without the freezing cans for the removal of the moisture from the outgoing air, the carbon dioxid and water in the outgoing air being determined both in a sample taken by the meter pump and also in a sample taken by an aspirator.

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[1] In the first of these two tests, less than 90 per cent of the water produced was recovered, but notwithstanding this the heat found was much too high. In the second of the two tests the results for carbon dioxid and water were both much too low. Since in general the results for carbon dioxid are very accurate and those for water tend to be too high, we have felt justified in rejecting these two check tests.

TABLE 226.—*Results of alcohol check tests.*

| Date. | Number of hours. | Weight of alcohol. | | Water. | | | | | Carbon dioxid. | | | | | Heat. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Results by meter pump. | | Results by aspirator. | | | Results by meter pump. | | Results by aspirator. | | | Results by meter pump. | | Results by aspirator. | | Results corrected for excess of water. | |
| | | Hydrated. | Anhydrous. | Computed. | Observed. | Percentage observed. | Observed. | Percentage observed. | Computed. | Observed. | Percentage observed. | Observed. | Percentage observed. | Computed. | Observed. | Percentage observed. | Observed. | Percentage observed. | Observed. | Percentage observed. |
| *Using copper freezing cans.* | | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Per cent.* | *Grams.* | *Per cent.* | *Grams.* | *Grams.* | *Per cent.* | *Grams.* | *Per cent.* | *Calories* | *Calories.* | *Per cent.* | *Calories.* | *Per cent.* | *Calories.* | *Per cent.* |
| Jan. 16, 1902. | 6 | 564.85 | 511.41 | 653.68 | 689.61 | 105.5 | ...... | ...... | 977.30 | 963.15 | 98.5 | ...... | ...... | 3,647.78 | 3,743.82 | 102.6 | ...... | ...... | 3,722.55 | 102.05 |
| Jan. 29, 1902. | 6 | 592.86 | 536.77 | 686.10 | 767.50 | 111.9 | ...... | ...... | 1,025.77 | 1,017.86 | 99.2 | ...... | ...... | 3,828.67 | 3,862.08 | 100.9 | ...... | ...... | 3,813.89 | 99.61 |
| Apr. 29, 1902. | 11 | 972.68 | 876.74 | 1,125.04 | 1,296.43 | 115.2 | ...... | ...... | 1,675.30 | 1,665.14 | 99.4 | ...... | ...... | 6,298.50 | 6,346.62 | 100.7 | ...... | ...... | 6,245.16 | 99.17 |
| Jan. 20, 1903. | 6 | 527.67 | 475.62 | 610.28 | 629.42 | 103.1 | ...... | ...... | 908.91 | 891.58 | 98.1 | ...... | ...... | 3,417.09 | [1]3,427.16 | 100.3 | ...... | ...... | 3,415.83 | 99.96 |
| Mar. 26, 1903. | 6 | 526.53 | 474.60 | 608.98 | 687.97 | 112.9 | ...... | ...... | 906.96 | 891.24 | 98.3 | ...... | ...... | 3,409.76 | [2]3,407.01 | 99.9 | ...... | ...... | 3,360.25 | 98.55 |
| Apr. 28, 1903. | 6 | 503.16 | 453.53 | 581.94 | 676.90 | 116.3 | ...... | ...... | 866.69 | 855.73 | 98.7 | ...... | ...... | 3,258.38 | [3]3,190.31 | 97.9 | ...... | ...... | 3,134.09 | 96.19 |
| Jan. 5, 1904. | 6 | 487.12 | 436.89 | 563.01 | 633.97 | 112.6 | ...... | ...... | 834.90 | 830.58 | 99.5 | ...... | ...... | 3,125.29 | 3,142.76 | 100.6 | ...... | ...... | 3,100.75 | 99.21 |
| Mar. 25, 1904. | 7 | 541.68 | 485.82 | 626.07 | 675.83 | 107.9 | ...... | ...... | 928.40 | 907.51 | 97.7 | ...... | ...... | 3,475.31 | 3,549.00 | 102.1 | ...... | ...... | 3,519.52 | 101.27 |
| Dec. 13, 1904. | 6 | 506.92 | 455.90 | 586.11 | 635.23 | 108.4 | ...... | ...... | 871.22 | 839.19 | 96.3 | ...... | ...... | 3,251.05 | 3,308.19 | 101.8 | ...... | ...... | 3,279.11 | 100.9 |
| Feb.10-11,1905 | 12 | 1,238.58 | 1,111.78 | 1,431.70 | 1,515.88 | 105.9 | ...... | ...... | 2,124.61 | 2,148.15 | 101.1 | ...... | ...... | 7,928.28 | 8,031.60 | 101.3 | ...... | ...... | 7,981.77 | 100.7 |
| May 9, 1905. | 10 | 939.94 | 843.73 | 1,086.50 | 1,211.84 | 111.5 | ...... | ...... | 1,612.37 | 1,597.93 | 99.1 | ...... | ...... | 6,016.70 | 6,090.58 | 101.2 | ...... | ...... | 6,016.78 | 100.0 |
| Jan. 12, 1906[4] | 8 | 750.76 | 671.07 | 867.32 | 890.72 | 102.7 | ...... | ...... | 1,282.41 | 1,278.49 | 99.7 | ...... | ...... | 4,785.45 | 4,826.07 | 100.9 | ...... | ...... | 4,812.22 | 100.56 |
| Totals.... | ...... | 8,152.75 | 7,333.86 | 9,426.73 | 10,311.30 | ...... | ...... | ...... | 14,014.84 | 13,886.55 | ...... | ...... | ...... | 52,442.26 | 52,925.20 | ...... | ...... | ...... | 52,401.92 | ...... |
| Averages. | ...... | 677.73 | 611.16 | 785.56 | 859.28 | 109.38 | ...... | ...... | 1,167.90 | 1,157.21 | 99.08 | ...... | ...... | 4,370.19 | 4,410.43 | 100.92 | ...... | ...... | 4,366.83 | 99.92 |
| *Without copper freezing cans.* | | | | | | | | | | | | | | | | | | | | |
| May 8, 1906. | 7.5 | 702.81 | 628.21 | 812.68 | 846.62 | 104.18 | 821.85 | 101.13 | 1,200.50 | 1,187.79 | 98.94 | 1,197.72 | 99.76 | 4,479.78 | 4,523.89 | 100.98 | 4,509.23 | 100.65 | 4,503.80 | 100.53 |
| Jan. 15, 1907. | 7 | 621.73 | 555.73 | 720.17 | 792.18 | 110.00 | 743.47 | 103.24 | 1,062.01 | 1,050.79 | 98.94 | 1,059.59 | 99.77 | 3,962.98 | 4,025.53 | 101.58 | 3,996.67 | 100.87 | 3,982.90 | 100.51 |
| May 3, 1907. | 8 | 706.23 | 627.68 | 815.26 | 922.88 | 113.20 | 833.63 | 102.25 | 1,199.50 | 1,198.82 | 99.94 | 1,201.46 | 100.16 | 4,476.05 | 4,559.31 | 101.87 | 4,506.48 | 100.68 | 4,495.60 | 100.43 |
| Nov. 12, 1907. | 9 | 809.95 | 716.98 | 931.23 | 960.04 | 103.1 | 886.50 | 95.2 | 1,370.14 | 1,363.68 | 99.53 | 1,368.91 | 99.92 | 5,112.81 | 5,137.65 | 100.5 | 5,094.48 | 99.6 | 5,120.74 | 100.10 |
| Nov. 17, 1908. | 8 | 676.40 | 601.17 | 780.82 | 866.18 | 110.9 | 829.00 | 106.2 | 1,148.89 | 1,138.04 | 99.0 | 1,146.18 | 99.8 | 4,286.98 | 4,310.68 | 100.6 | 4,288.85 | 100.05 | 4,260.57 | 99.40 |
| Apr. 15, 1909. | 8 | 666.89 | 593.76 | 770.02 | 807.19 | 104.8 | 725.38 | 94.2 | 1,134.73 | 1,121.89 | 98.9 | 1,131.32 | 99.7 | 4,234.13 | 4,241.08 | 100.1 | 4,193.06 | 99.00 | 4,219.26 | 99.70 |
| Totals.... | ...... | 4,184.01 | 3,723:53 | 4,830.18 | 5,195.09 | ...... | 4,839.83 | ...... | 7,115.77 | 7,061.01 | ...... | 7,105.18 | ...... | 26,552.73 | 26,798.14 | ...... | 26,588.77 | ...... | 26,582.87 | ...... |
| Averages. | ...... | 697.34 | 620.59 | 805.03 | 865.85 | 107.55 | 806.64 | 100.20 | 1,185.96 | 1,176.83 | 99.23 | 1,184.20 | 99.85 | 4,425.46 | 4,466.36 | 100.92 | 4,431.46 | 100.14 | 4,430.48 | 100.11 |
| *Both series.* | | | | | | | | | | | | | | | | | | | | |
| Totals........ | ...... | 12,336.76 | 11,057.39 | 14,256.91 | 15,506.39 | ...... | 4,839.83 | ...... | 21,130.61 | 20,947.56 | ...... | 7,105.18 | ...... | 78,994.99 | 79,723.36 | ...... | 26,588.77 | ...... | 78,984.79 | ...... |
| Averages..... | ...... | 685.38 | 614.30 | 792.05 | 861.47 | 108.76 | 806.64 | 100.2 | 1,173.92 | 1,163.75 | 99.13 | 1,184.20 | 99.85 | 4,388.61 | 4,420.07 | 100.92 | 4,431.46 | 100.14 | 4,388.04 | 99.99 |

[1] Capacity correction of −6 calories applied. [2] Capacity correction of +27 calories applied. [3] Capacity correction of +44 calories applied. [4] Freezing cans not used.

TABLE 227.—*Summary of results of alcohol check tests.*

| | Results with samples taken by meter pump. | Results on samples taken by aspirator. |
|---|---|---|
| Using copper freezing cans: | | |
| Carbon dioxid— | | |
| Average percentage recovered | 99.1 | ........... |
| Range of single results | ±2.4 | ........... |
| Water— | | |
| Average percentage recovered | 109.4 | ........... |
| Range of single results | ±6.8 | ........... |
| Heat— | | |
| Average percentage recovered | 100.9 | ........... |
| Range of single results | ±2.4 | ........... |
| Without copper freezing cans: | | |
| Carbon dioxid— | | |
| Average percentage recovered | 99.2 | 99.9 |
| Range of single results | ± .5 | ± .2 |
| Water— | | |
| Average percentage recovered | 107.6 | 100.2 |
| Range of single results | ±5.1 | ±6.0 |
| Heat— | | |
| Average percentage recovered | 100.9 | 100.1 |
| Range of single results | ± .9 | ± .9 |

The last two columns of Table 226 show the heat production corrected for the apparent error in the water determination. These results are obtained by adding to the heat as measured directly in the water current the latent heat of evaporation corresponding to the computed amount of water formed from the alcohol burned. On the average these results for heat agree very closely with the theoretical, the percentages recovered and the corresponding range of single results being:

| | Percentage recovered. | Range of single results. |
|---|---|---|
| With freezing cans | 99.92 | [1] ±2.93 |
| Without freezing cans | 100.11 | ±0.57 |
| Average of all | 99.99 | [1] ±2.93 |

[1] The omission of 1 result reduces this to 1.75.

Apparently the most serious error in the heat determinations lies in the measurement of the water vapor given off, and the more accurate determination of the latter by means of the aspirator samples reduces the average error to a very small amount, although it does not seem to materially reduce the range of the single results. The removal of the copper freezing cans appears not to have affected the average accuracy of the determinations. That the range of the single results is reduced may be due in part to increased experience in the use of the apparatus.

The experiments on animals in 1905 which are reported in this paper, as well as those described in previous publications, were made with the old form of apparatus, which, in the alcohol check tests, gave uniformly too high results for water. The effect of this, as already noted, is to make the results for heat also too high, but the error in animal experiments is relatively smaller—first, because it affects only the amount estimated for the latent heat of water vapor, which constituted only about one-fourth of the total heat measured, and, second, because the error appears to affect chiefly the first few hours of an experiment, and is therefore far less serious in an animal experiment extending over 48 hours than in an alcohol check test lasting for but 6 to 12 hours.

The excess of water vapor found in the samples taken by the meter pump seems to be due to a drying out of the sampling pans and especially of their rubber covers during the earlier hours of the experiment. The meter pump takes a sample of one two-hundredth of the total outgoing air. A comparatively small amount of residual moisture in the pans at the beginning of an experiment multiplied by the factor 200 will evidently cause a considerable error in the relatively short alcohol check experiments, while the effect on a long experiment would be inconsiderable.

That such is actually the case is shown by the results of those experiments upon animals in which results with the meter pump and the aspirator samples can be compared. Such of these results as are now available are contained in Table 228, the experiments being designated by their numbers simply.

TABLE 228.—*Comparison of results with meter pump and aspirator in experiments on animals.*

| Animal. | Period. | Subperiod. | Water. | | | $CO_2$. | | |
|---|---|---|---|---|---|---|---|---|
| | | | By meter pump. | By aspirator. | Excess by meter pump. | By meter pump. | By aspirator. | Excess by meter pump. |
| | *Experiment No. 207.* | | | | | | | |
| A. | Period I | 1 | 1,816.2 | 1,792.1 | + 24.1 | 2,178.7 | 2,173.0 | + 5.7 |
| | | 2 | 1,797.1 | 1,804.1 | − 7.0 | 2,171.7 | 2,167.1 | + 4.6 |
| | | 3 | 2,021.2 | 2,008.9 | + 12.3 | 2,188.6 | 2,174.6 | + 14.0 |
| | | 4 | 1,905.9 | 1,908.7 | − 2.8 | 2,177.8 | 2,186.5 | − 8.7 |
| B. | Period I | 1 | 1,830.9 | 1,843.8 | − 12.9 | 1,935.0 | 1,948.3 | − 13.3 |
| | | 2 | 1,867.0 | 1,858.4 | + 8.6 | 1,984.2 | 1,993.1 | − 8.9 |
| | | 3 | 1,817.8 | 1,861.9 | − 44.1 | 1,913.7 | 1,968.6 | − 54.9 |
| | | 4 | 1,838.0 | 1,838.8 | − .8 | 1,970.5 | 1,972.9 | − 2.4 |
| A. | Period II | 1 | 3,469.7 | 3,534.2 | − 64.5 | 3,114.6 | 3,138.6 | − 24.0 |
| | | 2 | 3,627.9 | 3,631.4 | − 3.5 | 3,193.8 | 3,169.3 | + 24.5 |
| | | 3 | 3,719.8 | 3,737.4 | − 17.6 | 3,150.9 | 3,180.0 | − 29.1 |
| | | 4 | 3,351.4 | 3,359.3 | − 7.9 | 3,089.6 | 3,106.0 | − 16.4 |
| B. | Period II | 1 | 3,074.6 | 3,117.8 | − 43.2 | 2,396.3 | 2,420.7 | − 24.4 |
| | | 2 | 2,982.8 | 2,998.8 | − 16.0 | 2,444.9 | 2,457.3 | − 12.4 |
| | | 3 | 3,244.7 | 3,240.1 | + 4.6 | 2,427.6 | 2,423.4 | + 4.2 |
| | | 4 | 3,139.2 | 3,154.4 | − 15.2 | 2,510.8 | 2,511.1 | − .3 |
| A. | Period III | 1 | 1,559.2 | 1,486.9 | + 72.3 | 1,558.2 | 1,571.4 | − 13.2 |
| | | 2 | 1,412.3 | 1,407.9 | + 4.4 | 1,548.7 | 1,565.7 | − 17.0 |
| | | 3 | 1,433.2 | 1,437.0 | − 3.8 | 1,534.4 | 1,535.2 | − .8 |
| | | 4 | 1,434.7 | 1,428.7 | + 6.0 | 1,533.0 | 1,537.0 | − 4.0 |
| B. | Period III | 1 | 1,828.6 | 1,764.6 | + 64.0 | 1,543.0 | 1,551.2 | − 8.2 |
| | | 2 | 1,721.2 | 1,723.7 | − 2.5 | 1,532.1 | 1,552.7 | − 20.6 |
| | | 3 | 1,799.7 | 1,788.4 | + 11.3 | 1,519.3 | 1,521.5 | − 2.2 |
| | | 4 | 1,715.7 | 1,708.8 | + 6.9 | 1,526.9 | 1,532.4 | − 5.5 |

TABLE 228.—*Comparison of results with meter pump and aspirator in experiments on animals*—Continued.

| Animal. | Period. | Subperiod. | Water. | | | CO₂. | | |
|---|---|---|---|---|---|---|---|---|
| | | | By meter pump. | By aspirator. | Excess by meter pump. | By meter pump. | By aspirator. | Excess by meter pump. |
| | *Experiment No. 207—Con.* | | | | | | | |
| A. | Period IV | 1 | 2,049.5 | 1,988.6 | + 60.9 | 2,004.2 | 2,018.8 | − 14.6 |
| | | 2 | 1,951.5 | 1,940.4 | + 11.1 | 2,033.4 | 2,039.7 | − 6.3 |
| | | 3 | 2,062.8 | 2,059.2 | + 3.6 | 2,032.9 | 2,038.7 | − 5.8 |
| | | 4 | 1,992.4 | 1,994.4 | − 2.0 | 2,023.7 | 2,031.6 | − 7.9 |
| B. | Period IV | 1 | 2,300.2 | 2,257.8 | + 42.4 | 1,952.8 | 1,964.9 | − 12.1 |
| | | 2 | 2,146.6 | 2,136.1 | + 10.5 | 1,990.6 | 1,985.8 | + 4.8 |
| | | 3 | 2,412.3 | 2,429.4 | − 17.1 | 1,939.2 | 1,949.8 | − 10.6 |
| | | 4 | 2,519.1 | 2,532.2 | − 13.1 | 1,973.3 | 1,986.5 | − 13.2 |
| | *Experiment No. 208.* | | | | | | | |
| E. | Period I | 1 | 1,565.8 | 1,509.6 | + 56.2 | 1,460.2 | 1,458.4 | + 1.8 |
| | | 2 | 1,376.1 | 1,384.4 | − 8.3 | 1,472.2 | 1,485.8 | − 13.6 |
| | | 3 | 1,413.2 | 1,391.5 | + 11.7 | 1,439.3 | 1,441.7 | − 2.4 |
| | | 4 | 1,304.6 | 1,317.7 | − 13.1 | 1,476.0 | 1,477.3 | − 1.3 |
| E. | Period II | 1 | 1,058.3 | 983.7 | + 74.6 | 1,048.8 | 1,063.4 | − 14.6 |
| | | 2 | 968.7 | 964.4 | + 4.3 | 1,063.5 | 1,059.3 | + 4.2 |
| | | 3 | 953.8 | 946.5 | + 7.3 | 1,035.0 | 1,031.1 | + 3.9 |
| | | 4 | 963.1 | 973.7 | − 10.6 | 1,102.9 | 1,112.9 | − 10.0 |
| E. | Period III | 1 | 901.2 | 863.4 | + 37.8 | 874.3 | 889.3 | − 15.0 |
| | | 2 | 838.8 | 831.4 | + 7.4 | 894.0 | 901.0 | − 7.0 |
| | | 3 | 890.2 | 889.5 | + .7 | 895.4 | 897.5 | − 2.1 |
| | | 4 | 838.2 | 842.7 | − 4.5 | 888.3 | 895.9 | − 7.6 |
| E. | Period IV | 1 | 1,812.8 | 1,769.7 | + 43.1 | 1,578.7 | 1,593.5 | − 14.8 |
| | | 2 | 1,615.7 | 1,630.9 | − 15.2 | 1,563.4 | 1,544.8 | + 18.6 |
| | | 3 | 1,709.3 | 1,700.7 | + 8.6 | 1,486.8 | 1,492.5 | − 5.7 |
| | | 4 | 1,487.8 | 1,499.4 | − 11.6 | 1,508.6 | 1,528.0 | − 19.4 |
| E. | Period V | 1 | 1,209.8 | 1,134.1 | + 75.7 | 1,090.8 | 1,103.6 | − 12.8 |
| | | 2 | 1,066.8 | 1,051.7 | + 15.1 | 1,091.1 | 1,099.2 | − 8.1 |
| | | 3 | 1,095.3 | 1,093.4 | + 1.9 | 1,084.7 | 1,091.1 | − 6.4 |
| | | 4 | 1,036.3 | 1,044.5 | − 2.8 | 1,095.5 | 1,103.9 | − 8.4 |
| E. | Period VI | 1 | 960.2 | 906.6 | + 53.6 | 847.9 | 859.6 | − 11.7 |
| | | 2 | 835.4 | 815.5 | + 19.9 | 823.1 | 826.9 | − 3.8 |
| | | 3 | 857.2 | 832.0 | + 25.2 | 829.2 | 819.8 | + 9.4 |
| | | 4 | 774.6 | 774.3 | + .3 | 819.8 | 825.1 | − 5.3 |
| D. | Period I | 1 | 1,405.7 | 1,283.0 | +122.7 | 978.6 | 991.8 | − 13.2 |
| | | 2 | 1,402.0 | 1,383.8 | + 18.2 | 955.2 | 955.9 | − .7 |
| | | 3 | 1,226.1 | 1,221.1 | + 5.0 | 948.0 | 957.7 | − 9.7 |
| | | 4 | 1,400.1 | 1,419.4 | − 19.3 | 983.9 | 991.3 | − 7.4 |
| D. | Period II | 1 | 984.2 | 925.8 | + 58.4 | 732.4 | 737.5 | − 5.1 |
| | | 2 | 897.8 | 888.5 | + 9.3 | 746.5 | 752.3 | − 5.8 |
| | | 3 | 858.1 | 851.3 | + 6.8 | 723.1 | 726.7 | − 3.6 |
| | | 4 | 797.9 | 801.3 | − 3.4 | 716.9 | 723.2 | − 6.3 |
| C. | Period II | 1 | 1,401.4 | 1,322.6 | + 78.8 | 1,287.9 | 1,298.6 | − 10.7 |
| | | 2 | 1,247.3 | 1,236.7 | + 10.6 | 1,286.1 | 1,288.4 | − 2.3 |
| | | 3 | 1,354.1 | 1,346.2 | + 7.9 | 1,341.3 | 1,338.5 | + 2.8 |
| | | 4 | 1,526.9 | 1,559.6 | − 32.7 | 1,442.7 | 1,451.7 | − 9.0 |

The error due to the evaporation of water from the pans would naturally affect principally or entirely the first subperiod of 12 hours and this is precisely what seems to have occurred. In experiment No. 208 there is an excess of water in the first subperiod as determined by the meter pump in every case, and in experiment No. 207, there is a similar excess in five cases out of eight, while there is no such difference in the results for carbon dioxid. The average excess of water found by the meter pump over that found by the aspirator in the first subperiod, omitting negative results, is 61.8 grams, or including all the negative results, 43.8 grams. In the remaining subperiods the excess of water found by the meter pump over that found by the aspirator is positive in 27 cases and negative in 24 cases, the average algebraic differences being:

| | Grams. |
|---|---|
| In experiment 207 | −3.1 |
| In experiment 208 | +1.4 |
| Average of all | − .7 |

In the later alcohol check tests previously tabulated, which are all short, corresponding in this respect to the first subperiods of the animal experiments, the average difference between the water vapor as determined by the meter pump and that determined by the aspirator was 59.2 grams, an amount agreeing well with the average excess found in the first subperiods of the animal experiments.

In the light of the foregoing results and discussion, we feel justified in concluding that the results of a single experiment with the respiration calorimeter may be regarded as accurate to within approximately the following percentages of the total amounts determined:

| | Per cent. |
|---|---|
| Carbon dioxid | 0.5 |
| Water (in aspirator samples) | 6.0 |
| Heat | 1.0 |

# APPENDIX.

## MEASUREMENTS, WEIGHTS, AND FEEDING RECORD OF ANIMALS.

TABLE I.—*Measurements of animals.*

| Date. | Chest girth. | Length from poll to root of tail. | Thickness at shoulder. | Thickness at paunch. | Thickness at hips. | Depth of chest. | Height of shoulder. |
|---|---|---|---|---|---|---|---|
| *Steer A.* | *Inches.* | *Inches.* | *Inches.* | *Inches.* | *Inches.* | *Inches.* | *Inches.* |
| Nov. 1, 1904 | 60.0 | 67.0 | 15.0 | 21.0 | 16.0 | 21.5 | 44.75 |
| Dec. 6, 1904 | 61.0 | 67.0 | 16.75 | 22.0 | 18.5 | 22.0 | 45.00 |
| June 5, 1905 | 62.5 | 69.0 | 16.0 | 19.75 | 16.0 | 21.0 | 44.5 |
| Feb. 1, 1905 | 61.0 | 67.0 | 15.75 | 20.25 | 16.25 | 22.0 | 45.0 |
| Mar. 1, 1905 | 62.5 | 66.0 | 16.25 | 20.25 | 16.0 | 21.5 | 44.0 |
| Apr. 3, 1905 | 61.25 | 66.0 | 15.25 | 20.0 | 15.25 | 22.0 | 45.25 |
| May 1, 1905 | 62.0 | [1] 66.75 | 16.0 | 20.5 | 16.25 | 23.0 | 46.25 |
| June 1, 1905 | 64.0 | 67.0 | 17.0 | 22.5 | 17.75 | 23.5 | 46.5 |
| July 3, 1905 | 63.5 | 70.0 | 16.75 | 22.0 | 16.5 | 23.25 | 47.5 |
| July 31, 1905 | 64.5 | 69.5 | 16.0 | 22.75 | 16.75 | 24.0 | 46.0 |
| Oct. 4, 1905 | 66.0 | 72.0 | 18.0 | 23.25 | 16.5 | 24.25 | 47.5 |
| Oct. 31, 1905 | 66.0 | 72.5 | 17.25 | 23.5 | 16.5 | 24.5 | 47.0 |
| Dec. 2, 1905 | 68.5 | 72.5 | 17.5 | 26.0 | 17.0 | 24.75 | 48.25 |
| Feb. 5, 1906 | 71.75 | 72.5 | 18.75 | 25.0 | 18.0 | 25.5 | 49.25 |
| Mar. 5, 1906 | 71.5 | 72.0 | 18.75 | 22.0 | 17.75 | 25.25 | 49.0 |
| Apr. 6, 1906 | 71.5 | 72.0 | 18.75 | 22.5 | 18.5 | 25.0 | 49.0 |
| May 5, 1906 | 72.0 | 72.0 | 18.75 | 25.75 | 18.0 | 25.75 | 49.5 |
| June 5, 1906 | 73.0 | 72.0 | 18.75 | 28.50 | [1] 19.0 | 26.0 | 49.5 |
| July 7, 1906 | 75.0 | 72.0 | 18.5 | 25.5 | [1] 21.0 | 26.5 | 50.0 |
| Aug. 6, 1906 | 74.5 | 73.0 | 17.5 | 22.5 | 17.5 | 25.5 | 50.0 |
| Sept. 8, 1906 | 73.0 | 73.5 | 17.5 | 22.5 | [1] 17.0 | 25.0 | 50.5 |
| Oct. 6, 1906 | 74.0 | 73.5 | 17.5 | 24.0 | 18.0 | 26.5 | 50.75 |
| Nov. 5, 1906 | 75.0 | 73.0 | 18.0 | 25.5 | 18.0 | 26.5 | 50.75 |
| Dec. 6, 1906 | 74.25 | 73.0 | 18.5 | 27.0 | 18.25 | 26.75 | 50.5 |
| Jan. 5, 1907 | 74.25 | 72.5 | 18.75 | 26.5 | 18.75 | 27.25 | 51.0 |
| Feb. 4, 1907 | 75.0 | 74.0 | 19.0 | 26.0 | 18.5 | 27.25 | 51.0 |
| Mar. 15, 1907 | 76.5 | 74.25 | 19.25 | 27.0 | 18.5 | 27.5 | 51.0 |
| Apr. 5, 1907 | 77.0 | 74.5 | 19.0 | 31.0 | 18.75 | 27.5 | 51.5 |
| May 9, 1907 | 76.5 | 74.5 | 19.5 | 28.5 | 18.75 | 27.75 | 51.5 |
| *Steer B.* | | | | | | | |
| Nov. 1, 1904 | 58.0 | 61.0 | 11.5 | 17.0 | 13.25 | 21.25 | 44.75 |
| Dec. 6, 1904 | 58.0 | 63.0 | 13.5 | 19.25 | 14.5 | 21.5 | 45.75 |
| Jan. 5, 1905 | 56.0 | 64.0 | 12.5 | 17.75 | 13.5 | 21.25 | 46.0 |
| Feb. 1, 1905 | 57.0 | 65.0 | 12.5 | 17.5 | 13.5 | 22.5 | 44.5 |
| Mar. 1, 1905 | 56.0 | 63.0 | 12.25 | 17.5 | 13.0 | 21.5 | 45.5 |
| Apr. 3, 1905 | 56.5 | 64.0 | 12.0 | 16.75 | 13.0 | 22.25 | 46.5 |
| May 1, 1905 | 58.0 | 63.5 | 12.75 | 16.25 | 13.5 | 21.5 | 46.0 |
| June 1, 1905 | 58.5 | 62.5 | 11.75 | 18.5 | 14.0 | 23.0 | 47.5 |
| July 3, 1905 | 59.0 | 63.5 | 14.0 | 19.0 | 14.5 | 22.0 | 48.25 |
| July 31, 1905 | 60.0 | 65.0 | 14.0 | 18.5 | 14.5 | 23.75 | 48.75 |
| Oct. 4, 1905 | 60.5 | 67.0 | 14.75 | 19.25 | 15.0 | 24.25 | 49.25 |
| Oct. 31, 1905 | 61.0 | 67.0 | 14.75 | 20.75 | 15.25 | 24.5 | 49.5 |
| Dec. 2, 1905 | 63.75 | 67.0 | 14.75 | 23.0 | 15.5 | 24.75 | 50.0 |
| Feb. 5, 1906 | 67.0 | 69.5 | 15.0 | 19.25 | 15.75 | 25.5 | 51.75 |
| Mar. 5, 1906 | 68.0 | 69.0 | 15.25 | 19.0 | 15.5 | 25.75 | 52.25 |
| Apr. 6, 1906 | 68.0 | 69.25 | 16.0 | 20.5 | 15.5 | 25.75 | 52.0 |
| May 5, 1906 | 68.0 | 70.0 | 15.5 | 20.0 | 16.25 | 25.5 | 52.0 |
| June 5, 1906 | 70.0 | 70.0 | 15.25 | 21.0 | 16.5 | 26.0 | 53.0 |
| July 7, 1906 | 70.5 | 70.0 | 15.75 | 20.5 | 16.5 | 26.75 | 53.0 |
| Aug. 6, 1906 | 70.5 | 70.0 | [1] 14.75 | 18.5 | 16.5 | [1] 25.5 | 53.0 |
| Sept. 8, 1906 | 71.0 | 71.0 | 15.0 | 19.0 | 16.0 | 26.0 | [1] 52.5 |
| Oct. 6, 1906 | 72.0 | 72.0 | 16.0 | 21.0 | 16.5 | 27.0 | 52.75 |
| Nov. 5, 1906 | 71.0 | 73.0 | 16.0 | 21.5 | 16.75 | 27.25 | 54.0 |
| Dec. 6, 1906 | 71.0 | 73.0 | 16.25 | 20.75 | 17.0 | 27.5 | 54.0 |
| Jan. 5, 1907 | 72.0 | 72.75 | 16.25 | 22.5 | 17.5 | 28.0 | 54.0 |
| Feb. 4, 1907 | 71.0 | 73.0 | 16.25 | 19.0 | 17.5 | 28.25 | 54.0 |
| Mar. 15, 1907 | 72.5 | 73.25 | 16.5 | 22.0 | 17.5 | 28.75 | 54.0 |
| Apr. 5, 1907 | 71.0 | 74.0 | 16.5 | 19.5 | 17.5 | 28.5 | 54.25 |
| May 9, 1907 | 71.5 | 73.5 | 16.25 | 21.5 | 17.5 | 28.5 | 54.5 |

[1] Probably some error.

TABLE II.—*Live weights.*

| Date. | Steer A. | Steer B. |
|---|---|---|
| 1904. | *Kilos.* | *Kilos.* |
| Sept. 29 | 243.2 | 170.4 |
| Sept. 30 | 244.1 | 169.1 |
| Oct. 1 | 250.9 | 171.8 |
| Oct. 2 | 248.6 | 173.2 |
| Oct. 3 | 245.9 | 170.7 |
| Oct. 7 | 253.2 | 175.5 |
| Oct. 14 | 249.3 | 177.3 |
| Oct. 21 | 253.9 | 180.5 |
| Oct. 28 | 254.1 | 180.7 |
| Oct. 29 | 254.1 | 180.2 |
| Nov. 4 | 259.1 | 192.0 |
| Nov. 11 | 268.6 | 194.0 |
| Nov. 18 | 276.4 | 200.2 |
| Nov. 28 | 273.6 | 191.8 |
| Nov. 29 | 275.0 | 208.6 |
| Nov. 30 | 260.0 | 208.2 |
| Dec. 1 | 270.4 | 207.2 |
| Dec. 2 | 273.6 | 207.5 |
| Dec. 3 | 270.9 | 211.8 |
| Dec. 4 | 278.1 | 217.2 |
| Dec. 5 | 282.4 | 220.4 |
| Dec. 6 | 279.5 | 218.1 |
| Dec. 7 | 280.8 | 218.8 |
| Dec. 8 | 284.5 | 217.2 |
| Dec. 9 | 279.0 | 216.3 |
| Dec. 10 | 283.6 | 220.4 |
| Dec. 12 | 280.0 | 212.0 |
| Dec. 13 | 280.0 | 211.3 |
| Dec. 14 | 281.2 | 208.0 |
| Dec. 17 | 284.8 | 207.2 |
| Dec. 18 | 280.0 | 201.0 |
| Dec. 19 | 280.0 | 207.2 |
| Dec. 29 | 278.5 | 204.2 |
| Dec. 30 | 277.8 | 206.8 |
| Dec. 31 | 280.8 | 206.0 |
| 1905. | | |
| Jan. 2 | 279.3 | |
| Jan. 3 | 274.3 | |
| Jan. 4 | 276.0 | |
| Jan. 5 | 271.4 | |
| Jan. 6 | 270.3 | |
| Jan. 7 | 270.5 | |
| Jan. 8 | 266.9 | |
| Jan. 9 | 266.0 | 204.3 |
| Jan. 10 | 270.8 | 199.0 |
| Jan. 11 | 270.1 | |
| Jan. 12 | 270.5 | |
| Jan. 13 | 270.7 | |
| Jan. 14 | 269.1 | |
| Jan. 15 | 268.4 | |
| Jan. 16 | 267.1 | |
| Jan. 17 | [1] 270.1<br>[2] 273.6 | 205.9 |
| Jan. 18 | | 196.5 |
| Jan. 19 | 268.0 | 200.0 |
| Jan. 20 | 262.4 | 202.0 |
| Jan. 21 | 271.4 | 199.5 |
| Jan. 22 | 278.4 | 199.3 |
| Jan. 23 | 266.1 | 196.2 |
| Jan. 24 | | [3] 197.3<br>[4] 197.2<br>[5] 195.6 |
| Jan. 26 | | 206.0 |
| Jan. 27 | | 201.0 |
| Jan. 28 | | 191.7 |
| Feb. 7 | 285.4 | |
| Feb. 8 | 280.1 | |
| Feb. 9 | 279.3 | |
| Feb. 10 | 279.0 | |
| Feb. 11 | 279.2 | |
| Feb. 12 | 282.0 | |
| Feb. 13 | 279.6 | |
| Feb. 14 | [3] 286.3<br>[2] 292.2 | |
| Feb. 15 | | 191.4 |
| Feb. 16 | 274.7 | 193.4 |
| Feb. 17 | 270.2 | 192.6 |
| Feb. 18 | 281.5 | 192.3 |
| Feb. 19 | | 194.4 |
| Feb. 20 | | 196.0 |
| Feb. 21 | | [3] 197.5<br>[5] 197.0 |
| Feb. 23 | | 193.0 |
| Feb. 24 | | 190.6 |
| Feb. 25 | | 193.0 |
| Feb. 28 | 278.0 | |
| Mar. 1 | 279.5 | |
| Mar. 2 | 281.3 | |
| Mar. 3 | 276.6 | |
| Mar. 4 | 273.4 | |
| Mar. 5 | 273.6 | |
| Mar. 6 | 270.4 | |
| Mar. 7 | 272.1 | |
| Mar. 9 | 267.8 | |
| Mar. 10 | 264.2 | |
| Mar. 11 | 264.4 | |
| Mar. 15 | | 198.4<br>[5] 197.4 |
| Mar. 16 | | 193.4 |
| Mar. 17 | | 193.5 |
| Mar. 18 | | 197.0 |
| Mar. 19 | | 193.5 |
| Mar. 20 | | 194.2 |
| Mar. 21 | 276.5 | 198.6<br>[5] 198.1 |
| Mar. 22 | 277.0 | |
| Mar. 23 | 275.2 | 182.2 |
| Mar. 24 | 278.2 | 179.4 |
| Mar. 25 | 275.3 | 189.9 |
| Mar. 26 | 273.3 | |
| Mar. 27 | 280.0 | |
| Mar. 28 | [3] 280.7<br>[5] 291.3 | |
| Mar. 30 | 280.7 | |
| Mar. 31 | 276.0 | |
| Apr. 1 | 274.2 | |
| Apr. 26 | | 201.0 |
| Apr. 27 | 269.0 | 196.3 |
| Apr. 28 | 284.0 | 194.6 |
| Apr. 29 | 281.3 | 195.6 |
| Apr. 30 | | 197.6 |
| May 1 | | 198.7 |
| May 2 | | [3] 200.0<br>[5] 205.4 |
| May 4 | | 196.2 |
| May 5 | | 194.5 |
| May 6 | 283.0 | 194.3 |
| May 29 | 314.0 | 217.0 |
| May 30 | 312.4 | 220.9 |
| May 31 | 310.5 | 217.5 |
| June 28 | 313.0 | 227.0 |
| June 29 | 315.4 | 228.4 |
| June 30 | 317.0<br>317.6 | 229.0<br>230.0 |
| July 1 | 315.0 | 230.7 |
| July 2 | 311.0 | 228.0 |
| July 3 | 310.0 | 229.0 |
| July 4 | 309.5 | 227.5 |
| July 5 | 310.5 | 231.0 |
| July 6 | 309.0 | 229.0 |
| July 7 | 309.0 | 231.5 |
| July 8 | 310.0 | 231.0 |
| July 9 | 312.0 | 231.5 |
| July 10 | 311.0 | 233.0 |
| July 11 | 313.0 | 234.0 |
| July 12 | 314.5 | 231.5 |
| July 13 | 314.0 | 233.0 |
| July 14 | 315.0 | 235.5 |
| July 15 | 315.0 | 234.0 |
| July 27 | 328.5 | 244.5 |
| July 28 | 334.0 | 241.5 |
| July 29 | 337.4 | 246.0 |
| Aug. 12 | 335.0 | 249.0 |
| Aug. 19 | 341.6 | 256.0 |
| Aug. 29 | 346.0 | 261.0 |
| Aug. 30 | 345.5 | 257.0 |
| Aug. 31 | 342.0 | 258.0 |
| Sept. 9 | 350.4 | 262.0 |
| Sept. 16 | 361.0 | 266.2 |
| Sept. 27 | 361.3 | 263.0 |
| Sept. 28 | 360.2 | 265.0 |

[1] 7 a. m.
[2] 1.30 p. m.
[3] 8 a. m.
[4] 10 a. m.
[5] 1 p. m.

TABLE II.—*Live weights*—Continued.

| Date. | Steer A. | Steer B. |
|---|---|---|
| 1905. | *Kilos.* | *Kilos.* |
| Sept. 29 | 358.4 | 262.4 |
| Oct. 7 | 360.4 | 256.6 |
| Oct. 14 | 360.6 | 263.4 |
| Oct. 21 | 354.0 | 275.0 |
| Oct. 28 | 360.6 | 275.4 |
| Oct. 30 | 363.0 | 285.0 |
| Oct. 31 | 372.4 | 290.0 |
| Nov 1 | 370.0 | 287.5 |
| Nov. 4 | 365.0 | 286.0 |
| Nov. 7 | 369.4 | 286.9 |
| Nov. 8 | 368.4 | 275.5 |
| Nov. 9 | 369.2 | 290.8 |
| Nov. 10 | 368.4 | 283.8 |
| Nov. 11 | 370.4 | 283.3 |
| Nov. 12 | 370.9 | 281.3 |
| Nov. 13 | 371.9 | 283.8 |
| Nov. 14 | 379.9 | 285.3 |
| Nov. 15 | 377.4 | 287.3 |
| Nov. 16 | 377.4 | 288.3 |
| Nov. 17 | 381.9 | 287.3 |
| Nov. 18 | 378.9 | 287.3 |
| Nov. 19 | 380.4 | 289.8 |
| Nov. 20 | 380.9 | 290.8 |
| Nov. 21 | 381.4 | 290.3 |
| Nov. 22 | 382.4 | 289.8 |
| Nov. 25 | 376.3 | 286.6 |
| Nov 27 | 385.0 | 295.0 |
| Nov. 28 | 387.5 | 296.4 |
| Nov. 29 | 389.5 | 299.0 |
| Dec. 9 | 395.2 | 307.7 |
| Dec. 29 | 404.0 | 305.9 |
| 1906. | | |
| Jan. 7 | 396.5 | .......... |
| Jan. 8 | 398.3 | .......... |
| Jan. 9 | 398.5 | .......... |
| Jan. 10 | 393.0 | .......... |
| Jan. 11 | 399.9 | .......... |
| Jan. 12 | 396.3 | .......... |
| Jan. 13 | 398.7 | 312.1 |
| Jan. 14 | 389.9 | 310.8 |
| Jan. 15 | 399.1 | 299.5 |
| Jan. 16 | 397.3 | 290.5 |
| Jan. 17 | 396.8 | 310.9 |
| Jan. 18 | 395.5 | 307.6 |
| Jan 19 | 391.2 | 306.5 |
| Jan. 20 | 400.0 | 305.0 |
| Jan. 21 | 397.5 | 305.0 |
| Jan. 22 | 401.0 | 305.0 |
| Jan. 23 | 411.5 | 304.4 |
| Jan. 24 | .......... | 295.0 |
| Jan. 25 | 407.7 | 298.2 |
| Jan. 26 | 399.6 | 301.4 |
| Jan. 27 | 406.4 | 298.4 |
| Jan. 28 | .......... | 290.0 |
| Jan. 29 | .......... | 300.9 |
| Jan. 30 | .......... | 296.2 |
| Jan. 31 | .......... | 301.0<br>[1] 297.6 |
| Feb. 2 | .......... | 301.6 |
| Feb. 9 | 420.9 | .......... |
| Feb. 10 | 415.0 | .......... |
| Feb. 11 | 417.4 | .......... |
| Feb. 12 | 419.2 | .......... |
| Feb. 13 | 420.8 | .......... |
| Feb. 14 | 418.0 | .......... |
| Feb. 15 | 422.0 | .......... |
| Feb. 16 | 417.2 | 316.0 |
| Feb. 17 | 421.8 | 318.6 |
| Feb. 18 | 417.0 | 314.0 |
| Feb. 19 | 422.0 | 316.4 |
| Feb. 20 | 425.7 | 307.8 |
| Feb. 21 | .......... | 309.3 |
| Feb. 22 | 424.6 | 316.1 |
| Feb. 23 | 410.0 | 312.2 |
| Feb. 24 | 424.6 | 310.4 |
| Feb. 25 | .......... | 310.9 |
| Feb. 26 | .......... | 309.5 |
| Feb. 27 | .......... | [2] 311.4 |
| 1906. | *Kilos.* | *Kilos.* |
| Mar. 1 | .......... | 311.5 |
| Mar. 2 | 419.9 | 303.6 |
| Mar. 3 | 410.0 | 310.7 |
| Mar. 4 | 421.0 | .......... |
| Mar. 5 | 410.2 | .......... |
| Mar. 6 | 395.6 | .......... |
| Mar. 7 | 410.2 | .......... |
| Mar. 8 | 398.6 | .......... |
| Mar. 9 | 408.6 | 304.4 |
| Mar. 10 | 398.2 | 295.6 |
| Mar. 11 | 397.2 | 300.0 |
| Mar. 12 | 398.3 | 301.5 |
| Mar. 13 | [2] 400.3 | 299.2 |
| Mar. 14 | .......... | 292.3 |
| Mar. 15 | [3] 404.1 | 298.2 |
| Mar. 16 | 397.0 | 296.3 |
| Mar. 17 | 397.9 | 298.2 |
| Mar. 18 | .......... | 293.7 |
| Mar. 19 | .......... | 291.4 |
| Mar. 20 | .......... | [2] 301.4 |
| Mar. 22 | .......... | 303.1 |
| Mar. 23 | 398.8 | 296.6 |
| Mar. 24 | 404.4 | 295.4 |
| Mar. 25 | 404.9 | .......... |
| Mar. 26 | 406.9 | .......... |
| Mar. 27 | 406.3 | .......... |
| Mar. 28 | 404.2 | .......... |
| Mar. 29 | 406.4 | .......... |
| Mar. 30 | 406.0 | 297.0 |
| Mar. 31 | 407.7 | 299.2 |
| Apr. 1 | 408.4 | 302.0 |
| Apr. 2 | 409.4 | 299.6 |
| Apr. 3 | [2] 412.6 | 305.5 |
| Apr. 4 | .......... | 305.3 |
| Apr. 5 | [3] 410.0 | 307.5 |
| Apr. 6 | 398.0 | 306.4 |
| Apr. 7 | 401.7 | 307.2 |
| Apr. 9 | .......... | 308.0 |
| Apr. 10 | .......... | [2] 312.6 |
| Apr. 12 | .......... | [4] 313.9 |
| Apr. 13 | .......... | 305.0 |
| Apr. 14 | 406.8 | 304.8 |
| Apr. 21 | 406.8 | 311.8 |
| Apr. 28 | 419.4 | 317.2 |
| Apr. 29 | 422.4 | 317.8 |
| Apr. 30 | 418.8 | 315.6 |
| May 5 | 434.6 | 317.4 |
| May 12 | 443.2 | 317.4 |
| May 19 | 444.6 | 328.8 |
| May 26 | 442.6 | 322.4 |
| May 28 | 452.0 | 325.2 |
| May 29 | 453.6 | 335.0 |
| May 30 | 454.4 | 327.4 |
| June 2 | 450.0 | 328.4 |
| June 9 | 450.8 | 330.0 |
| June 16 | 468.6 | 340.2 |
| June 19 | 456.0 | 338.4 |
| June 20 | 453.0 | 331.0 |
| June 21 | 453.8 | 340.2 |
| June 22 | 453.0 | 335.0 |
| June 23 | 458.0 | 335.2 |
| June 24 | 455.6 | 340.0 |
| June 25 | 459.6 | 334.0 |
| June 26 | 450.4 | 336.0 |
| June 27 | 451.0 | 338.4 |
| June 28 | 454.6 | 336.2 |
| June 29 | 451.4 | 339.2 |
| June 30 | 429.0 | 337.4 |
| July 1 | 447.4 | 342.2 |
| July 2 | 450.4 | 344.8 |
| July 3 | 457.8 | 343.2 |
| July 4 | 457.2 | 343.0 |
| July 5 | 458.6 | 342.6 |
| July 6 | 456.3 | 342.0 |
| July 14 | 450.6 | 334.0 |
| July 21 | 448.0 | 328.0 |
| July 28 | 456.6 | 335.4 |
| Aug. 4 | 456.2 | 329.6 |
| Aug. 11 | 447.4 | 330.0 |

[1] 1 p. m.

[2] 8.30 a. m.

[3] 6.16 p. m.

[4] 6.30 p. m.

TABLE II.—*Live weights*—Continued.

| Date. | Steer A. | Steer B. |
|---|---|---|
| 1906. | *Kilos.* | *Kilos.* |
| Aug. 18 | 443.4 | 333.2 |
| Aug. 25 | 447.2 | 332.0 |
| Sept. 1 | 448.2 | 337.6 |
| Sept. 8 | 439.4 | 337.8 |
| Sept. 15 | 442.2 | 334.6 |
| Sept. 22 | 442.4 | 337.2 |
| Sept 29 | 450.2 | 348.0 |
| Oct. 1 | 441.6 | 340.2 |
| Oct. 2 | 451.2 | 347.0 |
| Oct. 3 | 451.2 | 347.6 |
| Oct. 6 | 454.0 | 350.8 |
| Oct. 13 | 459.8 | 357.0 |
| Oct. 20 | 459.2 | 349.4 |
| Oct. 27 | 466.8 | 363.2 |
| Nov. 3 | 469.8 | 370.4 |
| Nov. 5 | 478.0 | 370.0 |
| Nov. 6 | 475.4 | 371.6 |
| Nov. 7 | 474.4 | 372.8 |
| Nov. 10 | 468.3 | 376.3 |
| Nov. 17 | 483.0 | 376.0 |
| Nov. 24 | 484.6 | 380.6 |
| Dec. 1 | 484.6 | 383.2 |
| Dec. 3 | 493.6 | 373.2 |
| Dec. 4 | 494.6 | 382.6 |
| Dec. 5 | 497.2 | 381.8 |
| Dec. 8 | 498.2 | 385.2 |
| Dec. 15 | 501.6 | 396.4 |
| Dec. 22 | 506.0 | 392.4 |
| Dec. 30 | 497.0 | 383.0 |
| Dec. 31 | 511.0 | 393.0 |
| 1907. | | |
| Jan. 1 | 504.6 | 392.6 |
| Jan. 3 | 489.8 | 388.2 |
| Jan. 12 | 480.8 | 367.0 |
| Jan. 19 | 492.4 | 363.8 |
| Jan. 23 | 497.6 | .......... |
| Jan. 24 | 483.2 | .......... |
| Jan. 25 | 487.6 | .......... |
| Jan. 26 | 493.0 | 374.8 |
| Jan. 27 | 483.2 | .......... |
| Jan. 28 | 497.0 | .......... |
| Jan. 29 | 497.6 | .......... |
| Jan. 30 | 493.6 | .......... |
| Jan. 31 | 497.8 | 367.0 |
| Feb. 1 | 500.0 | 366.8 |
| Feb. 2 | 500.0 | 369.2 |
| Feb. 3 | 500.4 | 373.0 |
| Feb. 4 | 500.0 | 363.0 |
| Feb. 5 | [1] 504.6 | 371.2 |
| Feb. 6 | .......... | 371.6 |
| Feb. 7 | 498.3 | [2] 370.4 |
| Feb. 8 | 489.0 | 372.0 |
| Feb. 9 | 499.0 | 363.0 |
| Feb. 10 | .......... | 371.2 |
| Feb. 11 | .......... | 371.0 |
| Feb. 12 | .......... | [3] 368.8<br>[4] 379.0 |
| Feb. 14 | .......... | [5] 373.6 |
| Feb. 15 | .......... | 365.2 |
| Feb. 16 | .......... | 365.8 |
| Feb. 21 | 516.8 | .......... |
| Feb. 22 | 518.0 | .......... |
| Feb. 23 | 517.8 | .......... |
| Feb. 24 | 519.6 | .......... |
| Feb. 25 | 519.4 | .......... |
| Feb. 26 | 517.4 | .......... |
| Feb. 27 | 516.4 | .......... |
| 1907. | *Kilos.* | *Kilos.* |
| Feb. 28 | 519.4 | 381.4 |
| Mar. 1 | 516.4 | 381.2 |
| Mar. 2 | 519.6 | 381.0 |
| Mar. 3 | 516.6 | 382.4 |
| Mar. 4 | 521.4 | 379.0 |
| Mar. 5 | [6] 528.0<br>[7] 536.0 | 384.2 |
| Mar. 6 | .......... | 384.6 |
| Mar. 7 | [6] 522.0 | 380.0 |
| Mar. 8 | 507.0 | 380.6 |
| Mar. 9 | 517.0 | 383.2 |
| Mar. 10 | 518.0 | 386.0 |
| Mar. 11 | 509.0 | 386.2 |
| Mar. 12 | 510.4 | [8] 391.2<br>[9] 392.0 |
| Mar. 13 | 510.4 | .......... |
| Mar. 15 | 522.0 | 380.6 |
| Mar. 16 | 522.0 | 388.0 |
| Mar. 17 | 513.0 | 389.6 |
| Mar. 18 | 516.0 | 380.2 |
| Mar. 19 | 519.4 | 380.0 |
| Mar. 20 | 515.4 | 396.8 |
| Mar. 21 | 509.0 | 385.0 |
| Mar. 22 | 510.4 | 375.2 |
| Mar. 23 | 510.2 | 382.0 |
| Mar. 21 | 509.4 | 368.0 |
| Mar. 25 | 509.0 | 372.0 |
| Mar. 26 | [10] 501.8<br>[11] 515.2 | 363.4 |
| Mar. 27 | .......... | 374.8 |
| Mar. 28 | [6] 511.0 | 378.6 |
| Mar. 29 | 503.6 | 372.0 |
| Mar. 30 | 509.0 | 377.0 |
| Mar. 31 | 493.0 | 374.0 |
| Apr. 1 | 500.8 | 372.4 |
| Apr. 2 | 499.0 | [10] 376.4<br>[7] 372.6 |
| Apr. 3 | 497.0 | .......... |
| Apr. 4 | 503.2 | [6] 376.8 |
| Apr. 5 | 505.0 | 368.0 |
| Apr. 6 | 508.0 | 374.4 |
| Apr. 7 | 506.6 | 371.4 |
| Apr. 8 | 511.6 | 370.0 |
| Apr. 9 | 512.0 | 373.2 |
| Apr. 10 | 512.2 | 373.0 |
| Apr. 11 | 513.4 | 386.0 |
| Apr. 12 | 511.0 | 378.4 |
| Apr. 13 | 510.4 | 382.0 |
| Apr. 14 | 514.0 | 379.6 |
| Apr. 15 | 515.8 | 384.6 |
| Apr. 16 | [10] 518.0<br>[9] 532.0 | 386.4 |
| Apr. 17 | .......... | 387.6 |
| Apr. 18 | [5] 518.4 | 387.6 |
| Apr. 19 | 506.2 | 381.8 |
| Apr. 20 | 513.0 | 384.6 |
| Apr. 21 | .......... | 383.8 |
| Apr. 22 | .......... | 383.2 |
| Apr. 23 | .......... | [10] 390.0<br>389.0 |
| Apr. 25 | .......... | [5] 389.6 |
| Apr. 26 | 511.0 | 379.4 |
| Apr. 27 | 514.6 | 383.4 |
| Apr. 28 | 517.0 | .......... |
| Apr. 29 | 520.4 | .......... |
| Apr. 30 | [12] 533.4<br>[13] 540.4 | .......... |
| May 1 | [6] 529.6 | .......... |

[1] 8.15 a. m.
[2] 6.15 p. m.
[3] 8 a. m.
[4] 1.15 p. m
[5] 6 p. m.
[6] 7.35 a. m.
[7] 1.20 p .m.
[8] 7.20 a. m.
[9] 1 p. m.
[10] 7.30 a. m.
[11] 1.10 p. m.
[12] 8.30 a. m.
[13] 3.10 p. m.

The following are the average monthly live weights which are shown graphically in figure 5:

TABLE IIa.—*Average live weights.*

| Steer A. | Weight. | Steer B. | Weight. |
|---|---|---|---|
| 1904. | *Kilos.* | 1904. | *Kilos.* |
| Sept. 29–Oct. 3 | 246.5 | Sept. 29–Oct. 3 | 171.0 |
| Nov. 4 | 259.1 | Nov. 4 | 192.0 |
| Nov. 29–Dec. 3 | 270.0 | Nov. 29–Dec. 3 | 208.7 |
| | | Dec. 29–31 | 205.7 |
| 1905. | | | |
| Dec. 30–Jan. 3 | 278.1 | 1905. | |
| Feb. 7–11 | 280.6 | Jan. 26–28 | 199.6 |
| Mar. 1–5 | 276.9 | Feb. 23–25 | 192.2 |
| Mar. 30–Apr. 1 | 277.0 | Mar. 23–25 | 183.8 |
| Apr. 27–29 | 278.1 | Apr. 28–May 2 | 198.4 |
| May 29–31 | 312.3 | May 29–31 | 218.5 |
| June 29–July 3 | 313.7 | June 29–July 3 | 229.0 |
| July 27–July 29 | 333.3 | July 27–29 | 244.0 |
| Aug. 29–31 | 344.5 | Aug. 29–31 | 258.7 |
| Sept. 27–29 | 360.0 | Sept. 27–29 | 263.5 |
| Oct. 30–Nov. 1 | 368.5 | Oct. 30–Nov. 1 | 287.5 |
| Nov. 27–29 | 387.3 | Nov. 27–29 | 296.8 |
| Dec. 29 | 404.0 | Dec. 29 | 305.9 |
| 1906. | | 1906. | |
| Jan. 25–27 | 404.6 | Jan. 29–Feb. 2 | 299.9 |
| Mar. 2–5 | 411.3 | Feb. 27–Mar. 3 | 309.3 |
| Mar. 30–Apr. 3 | 408.7 | Mar. 30–Apr. 3 | 300.7 |
| Apr. 28–30 | 420.2 | Apr. 28–30 | 316.9 |
| May 28–30 | 453.3 | May 28–30 | 329.2 |
| June 29–July 3 | 451.8 | June 29–July 3 | 341.4 |
| Aug. 4 | 456.2 | Aug. 4 | 329.6 |
| Sept. 1 | 448.2 | Sept. 1 | 337.6 |
| Oct. 1–3 | 448.0 | Oct. 1–3 | 344.9 |
| Nov. 3 | 469.0 | Nov. 3 | 370.4 |
| Dec. 1–5 | 492.5 | Dec. 1–5 | 380.2 |
| 1907. | | 1907. | |
| Dec. 30–Jan. 3 | 500.6 | Dec. 30–Jan. 3 | 389.2 |
| Jan. 31–Feb. 3 | 498.4 | Jan. 31–Feb. 3 | 369.0 |
| Feb. 27–Mar. 3 | 517.7 | Feb. 28–Mar. 4 | 381.0 |
| Mar. 30–Apr. 3 | 499.8 | Mar. 29–Apr. 2 | 374.4 |
| Apr. 27–May 1 | 523.0 | Apr. 25–27 | 384.1 |
| Oct. 28 | 592.8 | Oct. 28 | 427.8 |
| 1908. | | 1908. | |
| Jan. 4 | 631.4 | Jan. 4 | 482.2 |

TABLE III.—*Feeding record.*

| Date. | Length of feeding. | Kind of feed. | Hay. | | Grain. | | Air-dry matter. | Nitrogen. |
|---|---|---|---|---|---|---|---|---|
| | | | Steer A. | Steer B. | Steer A. | Steer B. | | |
| 1904. | *Days.* | | *Kilos.* | *Kilos.* | *Kilos.* | *Kilos.* | *Per cent.* | *Per cent.* |
| Oct. 1–31 | 31 | Mixed hay | 106.82 | 106.82 | | | [1] 91.80 | 1.873 |
| Do | 31 | Wheat bran | | | 7.57 | 5.28 | 92.10 | 2.475 |
| Do | 31 | Corn meal | | | 22.71 | 15.84 | 92.80 | 1.450 |
| Do | 31 | Linseed meal | | | 22.71 | 15.84 | 94.40 | 5.235 |
| Nov. 1–30 | 30 | Mixed hay | 109.09 | 109.09 | | | [1] 91.80 | [1] 1.873 |
| Do | 30 | Wheat bran | | | 7.62 | 5.41 | 92.10 | 2.475 |
| Do | 30 | Corn meal | | | 22.86 | 16.23 | 92.80 | 1.450 |
| Do | 30 | Linseed meal | | | 22.86 | 16.23 | 94.40 | 5.235 |
| Dec. 1–10 | 10 | Mixed hay | 36.29 | 36.29 | | | 91.80 | 1.873 |
| Do | 10 | Wheat bran | | | 2.535 | 1.265 | 91.50 | 2.460 |
| Do | 10 | Corn meal | | | 7.605 | 3.795 | 92.50 | 1.418 |
| Do | 10 | Linseed meal | | | 7.605 | 3.795 | 93.50 | 5.380 |
| Dec. 11–24 | 14 | Timothy hay [2] | 29.19 | 25.75 | | | [1] 92.36 | [1] .859 |
| Do | 14 | Wheat bran [2] | | | 21.050 | 15.450 | [1] 91.10 | [1] 2.530 |
| Dec. 25–31 | 7 | Timothy hay | 15.75 | 14.00 | | | 92.36 | .859 |
| Do | 7 | Wheat bran | | | 11.200 | 8.400 | 91.10 | 2.530 |

[1] Assumed.

[2] Amount gradually increased.

TABLE III.—*Feeding record*—Continued.

| Date. | Length of feeding. | Kind of feed. | Hay. | | Grain. | | Air-dry matter. | Nitrogen. |
|---|---|---|---|---|---|---|---|---|
| | | | Steer A. | Steer B. | Steer A. | Steer B. | | |
| 1905. | *Days.* | | *Kilos.* | *Kilos.* | *Kilos.* | *Kilos.* | *Per cent.* | *Per cent.* |
| Jan. 1-14 | 14 | Timothy hay | 31.50 | | | | 92.36 | .859 |
| Do | 14 | Wheat bran | | | 22.40 | | 91.10 | 2.530 |
| Jan. 15-21 | 7 | Timothy hay | 15.75 | | | | 91.21 | .880 |
| Do | 7 | Wheat bran | | | 11.20 | | 90.10 | 2.553 |
| Jan. 1-7 | 7 | Timothy hay | | 14.00 | | | [1] 92.36 | [1] .859 |
| Do | 7 | Wheat bran | | | | 8.40 | [1] 91.10 | 2.530 |
| Jan. 8-28 | 21 | Timothy hay | | 42.00 | | | 92.36 | .859 |
| Do | 21 | Wheat bran | | | | 25.20 | 91.10 | 2.530 |
| Jan. 22-28 | 7 | Timothy hay | 15.75 | | | | [1] 93.25 | [1] .860 |
| Do | 7 | Wheat bran | | | [2] 18.10 | | [1] 91.09 | [1] 2.616 |
| Jan. 29-Feb. 18 | 21 | Timothy hay | 47.25 | | | | 93.23 | .860 |
| Do | 21 | Wheat bran | | | 63.00 | | 91.09 | 2.616 |
| Feb. 19-Mar. 11 | 21 | Timothy hay | 47.25 | | | | 94.00 | .925 |
| Mar. 12-Apr. 1 | 21 | ....do | 90.50 | | | | 91.00 | .793 |
| Jan. 29-Feb. 4 | 7 | ....do | | 14.00 | | | [1] 94.00 | [1] .925 |
| Do | 7 | Wheat bran | | | | [3] 11.50 | [1] 91.09 | [1] 2.616 |
| Feb. 5-25 | 21 | Timothy hay | | 42.00 | | | 93.23 | .860 |
| Feb. 26-28 | 3 | ....do | | 6.00 | | | 93.23 | .860 |
| Do | 3 | Wheat bran | | | | 6.00 | [1] 91.09 | [1] 2.616 |
| Mar. 1-25 | 25 | Timothy hay | | 75.00 | | | 92.70 | .878 |
| Mar. 26-Apr. 7 | 13 | ....do | | 26.00 | | | [1] 92.70 | [1] .878 |
| Do | 13 | Wheat bran | | | | 3.215 | [1] 91.10 | 2.630 |
| Do | 13 | Corn meal | | | | 9.645 | [1] 92.50 | [1] 1.413 |
| Do | 13 | Linseed meal | | | | 9.645 | [1] 93.50 | [1] 5.380 |
| Apr. 8-13 | 6 | Timothy hay | | 12.00 | | | [1] 100.70 | [1] .870 |
| Do | 6 | Wheat bran | | | | 15.00 | [1] 98.00 | [1] 2.460 |
| Apr. 14-May 6 | 23 | Timothy hay | | 26.00 | | | 100.70 | .870 |
| Do | 23 | Wheat bran | | | | 26.00 | 98.00 | 2.460 |
| Apr. 2-May 2 | 32 | Timothy hay | 72.00 | | | | [1] 91.60 | [1] .793 |
| Do | 32 | Wheat bran | | | 10.285 | | 94.00 | 2.485 |
| Do | 32 | Corn meal | | | 30.855 | | 88.50 | 1.391 |
| Do | 32 | Linseed meal | | | 30.855 | | 97.70 | 5.439 |
| May 3-26 | 24 | Mixed hay | 110.75 | | | | [1] 98.04 | 1.803 |
| Do | 24 | Wheat bran | | | 8.555 | | 94.00 | 2.485 |
| Do | 24 | Corn meal | | | 25.665 | | 88.50 | 1.391 |
| Do | 24 | Linseed meal | | | 25.665 | | 97.70 | 5.439 |
| May 7-26 | 20 | Mixed hay | | 90.00 | | | [1] 98.04 | [1] 1.803 |
| Do | 20 | Wheat bran | | | | 5.555 | 94.00 | 2.485 |
| Do | 20 | Corn meal | | | | 16.665 | 88.50 | 1.391 |
| Do | 20 | Linseed meal | | | | 16.665 | 97.70 | 5.439 |
| May 27-June 30 | 35 | Mixed hay | 106.06 | 102.69 | | | [1] 98.04 | [1] 1.803 |
| Do | 35 | Wheat bran | | | 12.50 | 10.00 | 94.00 | 2.485 |
| Do | 35 | Corn meal | | | 37.50 | 30.00 | 88.50 | 1.391 |
| Do | 35 | Linseed meal | | | 37.50 | 30.00 | 97.70 | 5.439 |
| July 1-15 | 15 | Mixed hay | 42.00 | 42.00 | | | 92.50 | 2.020 |
| Do | 15 | Wheat bran | | | 5.40 | 4.275 | 98.00 | 2.400 |
| Do | 15 | Corn meal | | | 16.20 | 12.825 | 96.80 | 1.340 |
| Do | 15 | Linseed meal | | | 16.20 | 12.825 | 102.00 | 4.950 |
| July 16-18 | 3 | Mixed hay | 5.20 | 4.40 | | | [1] 92.50 | [1] 2.020 |
| July 16-28 | 13 | Alfalfa | 219.35 | 218.00 | | | 25.74 | 2.700 |
| July 29-Aug. 8 | 11 | Soja beans | 132.00 | 132.00 | | | 20.75 | 2.110 |
| Aug. 9-14 | 6 | Cowpeas | 72.00 | 72.00 | | | 14.26 | 2.750 |
| Aug. 15-31 | 17 | Kafir corn and cowpeas. | 204.00 | 204.00 | | | 16.57 | 1.370 |
| Sept. 1-5 | 5 | Alfalfa | 60.00 | 60.00 | | | 25.60 | 3.110 |
| Sept. 6-20 | 15 | Cowpeas | 180.00 | 180.00 | | | 15.70 | 2.880 |
| Sept. 21-Oct. 3 | 13 | Green corn | 156.00 | 156.00 | | | 12.00 | 1.830 |
| Oct. 4-5 | 2 | Clover and grass | 24.00 | 24.00 | | | 62.50 | 2.340 |
| Oct. 6-30 | 25 | Timothy hay | 79.83 | 70.88 | | | 99.23 | 1.210 |
| July 16-Aug. 2 | 18 | Wheat bran | | | 6.43 | 5.14 | 94.00 | 2.485 |
| Do | 18 | Corn meal | | | 19.29 | 15.42 | 88.50 | 1.391 |
| Do | 18 | Linseed meal | | | 19.29 | 15.42 | 97.70 | 5.439 |
| Aug. 3-Oct. 13 | 72 | Wheat bran | | | 25.715 | 20.57 | 97.26 | 2.515 |
| Do | 72 | Corn meal | | | 77.145 | 61.71 | 96.33 | 1.475 |
| Do | 72 | Linseed meal | | | 77.145 | 61.71 | 98.00 | 5.490 |
| Oct. 14-Nov. 6 | 24 | Wheat bran | | | 8.57 | 6.855 | 97.22 | 2.567 |
| Do | 24 | Corn meal | | | 25.710 | 20.565 | 92.00 | 1.440 |
| Do | 24 | Linseed meal | | | 25.710 | 20.565 | 95.00 | 6.000 |
| Oct. 31-Nov. 6 | 7 | Timothy with some clover. | 35.00 | 32.40 | | | 90.70 | 1.620 |
| Nov. 7-21 | 15 | ....do | 51.60 | 54.00 | | | 91.97 | 1.490 |
| Do | 15 | Wheat bran | | | 5.40 | 4.275 | 91.84 | 2.710 |
| Do | 15 | Corn meal | | | 16.20 | 12.825 | 91.25 | 1.490 |

[1] Assumed. [2] Amount gradually increased. [3] Started to increase, but stopped.

TABLE III.—*Feeding record*—Continued.

| Date. | Length of feeding. | Kind of feed. | Hay. | | Grain. | | Air-dry matter. | Nitrogen. |
|---|---|---|---|---|---|---|---|---|
| | | | Steer A. | Steer B. | Steer A. | Steer B. | | |
| 1905-6. | *Days.* | | *Kilos.* | *Kilos.* | *Kilos.* | *Kilos.* | *Per cent.* | *Per cent.* |
| Nov. 7-21 | 15 | Linseed meal | | | 16.20 | 12.825 | 94.52 | 5.930 |
| Nov. 22-Jan. 6 | 46 | Timothy with some clover. | 183.00 | | | | 90.70 | 1.620 |
| Nov. 22-Jan. 13 | 53 | do | | 210.00 | | | 90.70 | 1.620 |
| Nov. 22-Dec. 3 | 12 | Wheat bran | | | 4.035 | 2.925 | 97.22 | 2.567 |
| Do | 12 | Corn meal | | | 12.105 | 8.775 | 92.00 | 1.440 |
| Do | 12 | Linseed meal | | | 12.105 | 8.775 | 95.00 | 6.000 |
| Dec. 4-16 | 13 | Wheat bran | | | [1] 1.355 | 1.535 | 92.00 | 2.985 |
| Do | 13 | Corn meal | | | [1] 4.065 | 4.605 | 88.83 | 1.495 |
| Do | 13 | Linseed meal | | | [1] 4.065 | 4.605 | 94.00 | 5.885 |
| Dec. 4-21 | 18 | Wheat bran[3] | | | [2] 28.000 | 22.000 | 92.00 | 2.985 |
| Dec. 22-Jan. 6 | 16 | do | | | 3.285 | | 92.00 | 2.985 |
| Do | 16 | Corn meal | | | 18.885 | | 88.83 | 1.495 |
| Do | 16 | Linseed meal | | | 18.885 | | 94.00 | 5.885 |
| Dec. 22-Jan. 13 | 23 | Wheat bran | | | | 6.900 | 92.00 | 2.985 |
| Do | 23 | Corn meal | | | | 20.700 | 88.83 | 1.495 |
| Do | 23 | Linseed meal | | | | 20.700 | 94.00 | 5.885 |
| 1906. | | | | | | | | |
| Jan. 7-27 | 21 | Timothy hay | 63.00 | | | | 92.08 | 1.250 |
| Do | 21 | Wheat bran | | | 6.300 | | 91.50 | 2.953 |
| Do | 21 | Corn meal | | | 18.900 | | 87.50 | 1.647 |
| Do | 21 | Linseed meal | | | 18.900 | | 93.20 | 5.903 |
| Jan. 14-Feb. 3 | 21 | Timothy hay | | 58.80 | | | 92.08 | 1.250 |
| Do | 21 | Wheat bran | | | | 4.200 | 91.50 | 2.953 |
| Do | 21 | Corn meal | | | | 12.600 | 87.50 | 1.647 |
| Do | 21 | Linseed meal | | | | 12.600 | 93.20 | 5.903 |
| Jan. 28-Feb. 3 | 7 | Timothy hay | 21.00 | | | | 92.50 | 1.257 |
| Do | 7 | Wheat bran | | | [2] 4.023 | | 92.00 | 2.985 |
| Do | 7 | Corn meal | | | [2] 12.175 | | 88.83 | 1.495 |
| Do | 7 | Linseed meal | | | [2] 12.175 | | 94.00 | 5.885 |
| Feb. 4-24 | 21 | Timothy hay | 63.00 | | | | 92.50 | 1.257 |
| Do | 21 | Wheat bran | | | 14.700 | | 90.40 | 2.813 |
| Do | 21 | Corn meal | | | 44.100 | | 88.20 | 1.470 |
| Do | 21 | Linseed meal | | | 44.100 | | 93.10 | 5.547 |
| Feb. 4-10 | 7 | Timothy hay | | 19.60 | | | 92.50 | 1.257 |
| Do | 7 | Wheat bran | | | | [2] 3.055 | 91.50 | 2.953 |
| Do | 7 | Corn meal | | | | [2] 9.165 | 87.50 | 1.647 |
| Do | 7 | Linseed meal | | | | [2] 9.165 | 93.20 | 5.903 |
| Feb. 11-18 | 8 | Timothy hay | | 22.40 | | | 92.50 | 1.257 |
| Do | 8 | Wheat bran | | | | 4.000 | 90.40 | 2.813 |
| Do | 8 | Corn meal | | | | 12.000 | 88.20 | 1.470 |
| Do | 8 | Linseed meal | | | | 12.000 | 93.10 | 5.547 |
| Feb. 19-21 | 3 | Off feed | | | | | | |
| Feb. 22-Mar. 3 | 10 | Timothy hay | | 28.00 | | | 92.50 | 1.257 |
| Do | 10 | Wheat bran | | | | 3.570 | 90.40 | 2.813 |
| Do | 10 | Corn meal | | | | 10.720 | 88.20 | 1.470 |
| Do | 10 | Linseed meal | | | | 10.710 | 93.10 | 5.547 |
| Feb. 25-Mar. 17 | 21 | Timothy hay | 63.00 | | | | 94.99 | 1.157 |
| Mar. 4-24 | 21 | do | | 58.80 | | | 94.99 | 1.157 |
| Mar. 18-Apr. 7 | 21 | do | 105.00 | | | | 94.54 | 1.267 |
| Mar. 25-Apr. 14 | 21 | do | | 90.30 | | | 94.54 | 1.267 |
| Apr. 8-12 | 5 | Wheat bran | | | 2.000 | | 92.00 | 2.985 |
| Do | 5 | Corn meal | | | 6.000 | | 88.83 | 1.495 |
| Do | 5 | Linseed meal | | | 6.000 | | 94.00 | 5.885 |
| Apr. 8-May 18 | 41 | Mixed hay | 212.40 | | | | 90.70 | 1.620 |
| Apr. 13-May 1 | 19 | Wheat bran | | | 10.640 | | 93.30 | 2.806 |
| Do | 19 | Corn-and-cob meal | | | 31.920 | | 93.50 | 1.375 |
| Do | 19 | Linseed meal | | | 10.640 | | 97.20 | 5.391 |
| Apr. 15-May 18 | 34 | Mixed hay | | 174.70 | | | 90.70 | 1.620 |
| Apr. 15-May 1 | 17 | Wheat bran | | | | 7.140 | 93.30 | 2.806 |
| Do | 17 | Corn-and-cob meal | | | | 21.420 | 93.50 | 1.375 |
| Do | 17 | Linseed meal | | | | 7.140 | 97.20 | 5.391 |
| May 2-June 1 | 31 | Wheat bran | | | 18.228 | 13.276 | 93.30 | 2.806 |
| Do | 31 | Corn-and-cob meal | | | 54.684 | 39.828 | 93.50 | 1.375 |
| Do | 31 | Linseed meal | | | 18.228 | 13.276 | 97.20 | 5.391 |
| May 19-June 19 | 32 | Mixed hay | 179.20 | 144.60 | | | 98.14 | 1.803 |
| June 2-12 | 11½ | Wheat bran | | | 7.301 | 5.117 | 93.30 | 2.806 |
| Do | 11½ | Corn-and-cob meal | | | 21.903 | 15.351 | 93.50 | 1.375 |
| Do | 11½ | Linseed meal | | | 7.301 | 5.117 | 97.20 | 5.391 |
| June 13-19 | 6½ | Wheat bran | | | 4.125 | 2.995 | 92.60 | 2.743 |
| Do | 6½ | Corn-and-cob meal | | | 12.375 | 8.985 | 91.50 | 1.398 |
| Do | 6½ | Linseed meal | | | 4.125 | 2.995 | 96.30 | 5.278 |
| June 20-July 6 | 17 | Mixed hay | 87.04 | 69.36 | | | 98.04 | 1.803 |
| Do | 17 | Wheat bran | | | 10.794 | 7.819 | 96.00 | 2.716 |
| Do | 17 | Corn-and-cob meal | | | 32.382 | 23.457 | 95.30 | 1.336 |
| Do | 17 | Linseed meal | | | 10.794 | 7.819 | 96.30 | 5.626 |

[1] Amount gradually decreased. [2] Amount gradually increased. [3] Fed in addition to mixture.

TABLE III.—*Feeding record*—Continued.

| Date. | Length of feeding. | Kind of feed. | Hay. | | Grain. | | Air-dry matter. | Nitrogen. |
|---|---|---|---|---|---|---|---|---|
| | | | Steer A. | Steer B. | Steer A. | Steer B. | | |
| 1905-6. | *Days.* | | *Kilos.* | *Kilos.* | *Kilos.* | *Kilos.* | *Per cent.* | *Per cent.* |
| July 6-9 | 3 | Timothy and clover. | 18.00 | 15.00 | | | 48.80 | 1.395 |
| July 10-17 | 8 | Oats and peas | 54.00 | 54.00 | | | 18.19 | 2.575 |
| July 18-21 | 4 | Alfalfa | 28.00 | 28.00 | | | 27.37 | 2.660 |
| July 22-Aug. 4 | 14 | Ensilage (mixed hay). | 98.00 | 103.50 | | | 30.20 | [1] 1.995 |
| Aug. 5-22 | 18 | Corn | 137.00 | 154.00 | | | 16.79 | 1.905 |
| Aug. 23-29 | 7 | Alfalfa | 49.00 | 56.00 | | | 20.71 | 2.745 |
| Aug. 30-Sept. 3 | 5 | Cowpeas | 35.00 | 40.00 | | | 17.16 | 2.590 |
| Sept. 4-8 | 5 | Alfalfa | 35.00 | 40.00 | | | 28.36 | 2.550 |
| Sept. 9-22 | 14 | Kafir corn and cowpeas. | 122.00 | 136.00 | | | 13.34 | 1.837 |
| Sept. 23-Oct. 1 | 9 | Corn | 92.00 | 101.00 | | | [1] 16.79 | [1] 1.905 |
| Oct. 2-5 | 5 | Grass | 44.00 | 48.00 | | | [1] 62.50 | 2.340 |
| Oct. 6-10 | 5 | Alfalfa | 55.00 | 60.00 | | | 20.52 | 2.670 |
| Oct. 11-13 | 3 | Corn | 33.00 | 36.00 | | | [1] 12.00 | 1.830 |
| Oct. 14-26 | 12½ | Ensilage [2] | 137.00 | 150.00 | | | 25.90 | [1] 1.220 |
| Oct. 26-Nov. 30 | 35½ | ....do. [2] | 216.00 | 216.00 | | | 25.90 | [1] 1.220 |
| 1906. | | | | | | | | |
| July 7-14 | 8 | Wheat bran | | | 3.997 | 3.199 | 92.60 | 2.743 |
| Do | 8 | Corn-and-cob meal | | | 11.991 | 9.597 | 91.50 | 1.398 |
| Do | 8 | Linseed meal | | | 3.997 | 3.199 | 96.30 | 5.278 |
| July 15-31 | 17 | Wheat bran | | | 8.001 | 7.490 | 92.60 | 2.743 |
| Do | 17 | Corn-and-cob meal | | | 24.003 | 22.470 | 91.50 | 1.398 |
| Do | 17 | Linseed meal | | | 8.001 | 7.490 | 96.30 | 5.278 |
| Aug. 1-Oct. 4 | 65 | Wheat bran [3] | | | 54.165 | 50.700 | 98.00 | 2.634 |
| Do | 65 | Corn-and-cob meal | | | 108.330 | 101.400 | 81.00 | 1.071 |
| Oct. 27-Dec. 1 | 36 | Mixed hay | 99.60 | 79.20 | | | 98.04 | 1.803 |
| Oct. 5-Dec. 1 | 58 | Wheat bran | | | 48.330 | 46.400 | 98.00 | 2.604 |
| Do | 58 | Corn-and-cob meal | | | 96.660 | 92.800 | 81.00 | 1.258 |
| Dec. 2-15 | 14 | Wheat bran | | | 4.665 | 4.665 | 98.00 | 2.604 |
| Do | 14 | Corn-and-cob meal | | | 9.330 | 9.330 | 81.00 | 1.258 |
| Do | 14 | Mixed hay | 97.00 | 81.40 | | | 98.04 | 1.803 |
| Dec. 16-31 | 16 | ....do | 102.20 | 99.60 | | | 98.04 | 1.803 |
| 1907. | | | | | | | | |
| Jan. 1-9 | 9 | .....do | 30.60 | | | | 98.04 | 1.803 |
| Jan. 1-17 | 17 | .....do | | 76.00 | | | 98.04 | 1.803 |
| Jan. 10-19 | 9½ | Timothy hay | 32.30 | | | | [1] 90.70 | 1.130 |
| Jan. 18-26 | 9 | .....do | | 28.80 | | | [1] 90.70 | 1.130 |
| Jan. 1-19 | 18½ | Wheat bran [4] | | | 5.020 | | 89.70 | 2.847 |
| Do | 18½ | Corn meal | | | 15.060 | | 89.90 | 1.598 |
| Do | 18½ | Linseed meal | | | 15.060 | | 91.30 | 5.537 |
| Jan. 7-26 | 20 | Wheat bran | | | | 4.095 | 89.70 | 2.847 |
| Do | 20 | Corn meal | | | | 12.285 | 89.90 | 1.598 |
| Do | 20 | Linseed meal | | | | 12.285 | 91.30 | 5.537 |
| Jan. 20-Feb. 9 | 21 | Timothy hay | 71.40 | | | | 90.70 | 1.150 |
| Do | 21 | Wheat bran | | | 7.035 | | 89.70 | 2.847 |
| Do | 21 | Corn meal | | | 21.000 | | 89.90 | 1.598 |
| Do | 21 | Linseed meal | | | 21.000 | | 91.30 | 5.537 |
| Jan. 27-Feb. 16 | 21 | Timothy hay | | 67.20 | | | 90.70 | 1.130 |
| Do | 21 | Wheat bran | | | | 4.935 | 89.70 | 2.847 |
| Do | 21 | Corn meal | | | | 14.700 | 89.90 | 1.598 |
| Do | 21 | Linseed meal | | | | 14.700 | 91.30 | 5.537 |
| Feb. 10-16 | 7 | Timothy hay | 23.00 | | | | [1] 91.00 | [1] 1.100 |
| Do | 7 | Wheat bran | | | [3] 4.365 | | [1] 88.20 | 2.867 |
| Do | 7 | Corn meal | | | 13.095 | | [1] 88.70 | [1] 1.628 |
| Do | 7 | Linseed meal | | | 13.095 | | [1] 91.80 | [1] 5.531 |
| Feb. 17-23 | 7 | Timothy hay | | 22.40 | | | [1] 91.00 | [1] 1.100 |
| Do | 7 | Wheat bran | | | | [3] 2.575 | [1] 88.20 | 2.867 |
| Do | 7 | Corn meal | | | | 7.725 | [1] 88.70 | [1] 1.628 |
| Do | 7 | Linseed meal | | | | 7.725 | [1] 91.80 | [1] 5.531 |
| Feb. 17-Mar. 9 | 21 | Timothy hay | 71.40 | | | | 91.00 | 1.100 |
| Do | 21 | Wheat bran | | | 16.800 | | 88.20 | 2.867 |
| Do | 21 | Corn meal | | | 50.400 | | 88.70 | 1.628 |
| Do | 21 | Linseed meal | | | 50.400 | | 91.80 | 5.531 |
| Feb. 24-Mar. 16 | 21 | Timothy hay | | 67.20 | | | 91.00 | 1.100 |
| Do | 21 | Wheat bran | | | | 9.450 | 88.20 | 2.867 |
| Do | 21 | Corn meal | | | | 28.350 | 88.70 | 1.628 |
| Do | 21 | Linseed meal | | | | 28.350 | 91.80 | 5.531 |
| Mar. 10-30 | 21 | Timothy hay | 71.40 | | | | 92.40 | 1.099 |
| Mar. 17-Apr. 6 | 21 | .....do | | 67.20 | | | 92.40 | 1.099 |
| Mar. 31-Apr. 20 | 21 | .....do | 117.60 | | | | 91.80 | 1.138 |
| Apr. 7-27 | 21 | .....do | | 111.30 | | | 91.80 | 1.138 |

[1] Assumed.

[2] Ensilage fed one meal, hay the other.

[3] Change of mixture: One-third bran; two-thirds corn-and-cob meal.

[4] Special mixture.

## RESPIRATION CALORIMETER EXPERIMENTS OF 1905.

TABLE IV.—*Live weights, water consumed, weights of excreta, and rectal temperatures.*

| Date. | Live weight. | Water consumed. | Weight of feces. | Weight of urine. | Rectal temperature. |
|---|---|---|---|---|---|
| *Period I.* | | | | | |
| **Steer A:** | *Kilos.* | *Kilos.* | *Grams.* | *Grams.* | ° *C.* |
| Jan. 5 | 271.4 | 10.2 | 8,760 | 2,750 | 37.9 |
| 6 | 270.3 | 12.1 | 6,550 | 2,655 | 37.1 |
| 7 | 270.5 | 12.2 | 7,380 | 2,940 | 36.7 |
| 8 | 266.9 | 15.4 | 8,600 | 3,310 | 37.2 |
| 9 | 266.0 | 18.0 | 8,480 | 2,490 | 38.8 |
| 10 | 270.8 | 14.0 | 8,540 | 3,470 | 39.1 |
| 11 | 270.1 | 13.9 | 7,615 | 3,185 | 36.8 |
| 12 | 270.5 | 11.8 | 7,380 | 3,335 | 37.2 |
| 13 | 270.7 | 12.8 | 7,785 | 3,065 | 37.4 |
| 14 | 269.1 | 11.9 | 8,080 | 3,530 | 37.0 |
| 15 | 268.4 | 11.3 | 7,240 | 3,550 | 37.9 |
| 16 | 267.1 | 11.9 | 8,005 | 3,425 | 37.2 |
| 17 | [1] 270.1 | 12.0 | 6,745 | 2,645 | 37.0 |
| 17 | [2] 273.6 | | | | 36.7 |
| 18 | | | 6,830 | 3,585 | |
| 19 | [3] 268.0 | | 4,540 | 2,725 | |
| 20 | [4] 262.4 | 22.5 | 8,135 | 2,640 | 38.0 |
| 21 | [4] 271.4 | 13.6 | 6,635 | 2,930 | 38.8 |
| 22 | [5] 278.4 | | 8,160 | 2,755 | |
| Total | | | 135,460 | 54,985 | |
| Spilled in calorimeter and stall— | | | | | |
| Jan. 19 | | | 25.0 | 353.7 | |
| 21 | | | | 745.0 | |
| 22 | | | | 550.4 | |
| 23 | | | 9.2 | | |
| From duct— | | | | | |
| Jan. 19 | | | 48.2 | | |
| **Steer B:** | | | | | |
| Jan. 19 | 200.0 | 10.1 | 6,220 | 2,515 | 37.2 |
| 20 | 202.0 | 8.7 | 6,275 | 2,390 | 38.2 |
| 21 | 199.5 | 10.5 | 5,645 | | 38.0 |
| 22 | 199.3 | 6.9 | 5,930 | 2,260 | 38.5 |
| 23 | 196.2 | 7.1 | 4,730 | 4,070 | 37.4 |
| 24 | [4] 197.3 | | 4,995 | 2,765 | 36.1 |
| 25 | | | 4,265 | 1,125 | |
| 26 | [3] 206.0 | | 5,650 | 1,820 | |
| 27 | [4] 201.0 | | 6,400 | 1,905 | 36.7 |
| 28 | [6] 191.7 | 2.9 | 5,155 | 1,825 | 37.5 |
| Total | | | 55,265 | 20,675 | |
| Spilled in calorimeter— | | | | | |
| Jan. 26 | | | 66.7 | 292.5 | |
| From ducts— | | | | | |
| Jan. 27 | | | 42.0 | | |
| 28 | | | 16.2 | | |
| *Period II.* | | | | | |
| **Steer A:** | | | | | |
| Feb. 7 | 285.4 | 8.3 | | | |
| 8 | 280.1 | 13.3 | | | 36.2 |
| 9 | 279.3 | 16.1 | 10,530 | 4,290 | 38.1 |
| 10 | 279.0 | 17.4 | 9,555 | 4,605 | 38.9 |
| 11 | 279.2 | 20.8 | 9,560 | 6,725 | 38.1 |
| 12 | 282.0 | 15.1 | 9,725 | | 38.4 |
| 13 | 279.6 | 18.4 | 9,880 | | 38.0 |
| 14 | [4] 286.3 | 11.0 | 11,025 | 4,985 | 38.7 |
| 14 | 292.2 | | | | 37.5 |
| 15 | | | 8,730 | 3,995 | |
| 16 | [7] 274.7 | | 9,040 | 3,920 | 38.0 |
| 17 | [8] 270.2 | 27.0 | 7,475 | | 39.2 |
| 18 | 281.5 | 18.5 | 9,320 | 3,790 | 39.0 |
| Total | | | 94,840 | 32,310 | |
| Spilled in calorimeter and stall— | | | | | |
| Feb. 17 | | | 629.4 | | |
| 18 | | | | 449.2 | |
| 18 | | | | 110.0 | |
| From duct— | | | | | |
| Feb. 16 | | | 370.2 | | |
| 18 | | | 378.3 | | |

[1] At 7 a. m.
[2] At 1.30 p. m.
[3] At 6 p. m.
[4] At 8 a. m.
[5] At 12 m.
[6] At 1 p. m.
[7] At 8.30 p. m.
[8] At 11 a. m.

TABLE IV.—*Live weights, water consumed, weights of excreta, and rectal temperatures*—Continued.

| Date. | Live weight. | Water consumed. | Weight of feces. | Weight of urine. | Rectal temperature. |
|---|---|---|---|---|---|
| *Period II*—Continued. | | | | | |
| Steer B: | *Kilos.* | *Kilos.* | *Grams.* | *Grams.* | °*C.* |
| Apr. 27 | 196.3 | 7.3 | 5,960 | 2,740 | 38.3 |
| 28 | 194.6 | 11.1 | 6,470 | 2,580 | 38.5 |
| 29 | 195.6 | 11.7 | 8,440 | 2,300 | 39.0 |
| 30 | 197.6 | 10.4 | 7,250 | ........ | 38.6 |
| May 1 | 198.7 | 6.3 | 6,730 | 2,130 | 38.1 |
| 2 | [1] 205.4 | 8.2 | 6,380 | 2,075 | 38.8 |
| 2 | ........ | ........ | ........ | ........ | 38.7 |
| 3 | ........ | ........ | 4,660 | 2,505 | ........ |
| 4 | [2] 196.2 | ........ | 9,950 | 1,655 | 38.5 |
| 5 | [1] 194.5 | 11.6 | 5,540 | 2,700 | 39.0 |
| 6 | 194.3 | 17.7 | 7,220 | 2,580 | 38.7 |
| Total | ........ | ........ | 68,600 | 21,265 | ........ |
| Spilled in calorimeter and stall— | | | | | |
| May 5 | ........ | ........ | 54.6 | 408.3 | ........ |
| 5 | ........ | ........ | ........ | 2,036.0 | ........ |
| From duct— | | | | | |
| May 4 | ........ | ........ | 179.5 | ........ | ........ |
| 6 | ........ | ........ | 42.0 | ........ | ........ |
| *Period III.* | | | | | |
| Steer A: | | | | | |
| Mar. 2 | 281.3 | 9.0 | 4,150 | 3,095 | 38.7 |
| 3 | 276.6 | 4.7 | 4,910 | 5,145 | 38.7 |
| 4 | 273.4 | 10.0 | 4,505 | 3,750 | 38.2 |
| 5 | 273.6 | 5.6 | 4,375 | 5,070 | 38.1 |
| 6 | 270.4 | 8.4 | 3,895 | 3,330 | 37.7 |
| 7 | [1] 272.1 | 8.1 | 4,110 | 3,160 | 38.4 |
| 7 | [2] 276.6 | ........ | ........ | ........ | 38.3 |
| 8 | ........ | ........ | 4,235 | 2,615 | ........ |
| 9 | [2] 267.6 | ........ | 5,190 | 1,730 | 39.1 |
| 10 | [1] 264.2 | 12.0 | 3,800 | 3,140 | 39.0 |
| 11 | 264.4 | 12.5 | 5,235 | 4,960 | 37.6 |
| Total | ........ | ........ | 44,405 | 35,995 | ........ |
| Spilled in calorimeter and stall— | | | | | |
| Mar. 10 | ........ | ........ | 25.2 | 256.9 | ........ |
| From duct— | | | | | |
| Mar. 9 | ........ | ........ | 158.5 | ........ | ........ |
| 11 | ........ | ........ | 9.0 | ........ | ........ |
| Steer B: | | | | | |
| Feb. 16 | 193.4 | 5.6 | 3,290 | 1,585 | 37.8 |
| 17 | 192.6 | 4.6 | 3,160 | 1,565 | 38.3 |
| 18 | 192.3 | 5.7 | 2,610 | 1,470 | 37.5 |
| 19 | 194.4 | 7.2 | 3,200 | 1,100 | 38.5 |
| 20 | 196.0 | 6.0 | 4,410 | 1,580 | 38.6 |
| 21 | [1] 197.5 | 1.8 | 4,040 | 1,655 | 38.6 |
| 21 | 197.0 | ........ | ........ | ........ | 38.7 |
| 22 | ........ | ........ | 3,035 | 1,395 | ........ |
| 23 | [2] 193.0 | ........ | 4,910 | 1,375 | 38.9 |
| 24 | [1] 190.6 | 10.0 | 3,205 | 1,285 | 38.6 |
| 25 | 193.0 | 3.0 | 4,690 | 1,655 | 38.2 |
| Total | ........ | ........ | 36,550 | 14,665 | ........ |
| Spilled in calorimeter and stall— | | | | | |
| Feb. 24 | ........ | ........ | 1.4 | ........ | ........ |
| From duct— | | | | | |
| Feb. 23 | ........ | ........ | 10.8 | ........ | ........ |
| 25 | ........ | ........ | 21.4 | ........ | ........ |
| *Period IV.* | | | | | |
| Steer A: | | | | | |
| Mar. 23 | 275.2 | 14.8 | 8,535 | 2,165 | 38.7 |
| 24 | 278.2 | 10.5 | 9,505 | 1,950 | 38.8 |
| 25 | 275.3 | 11.2 | 9,845 | 2,645 | 38.6 |
| 26 | 273.3 | 10.5 | 10,125 | 2,440 | 38.8 |
| 27 | 280.0 | 12.1 | 11,385 | 1,995 | 38.1 |
| 28 | [1] 280.7 | 14.1 | 10,460 | 2,365 | 38.6 |
| 28 | 291.3 | ........ | ........ | ........ | 38.2 |
| 29 | ........ | ........ | 9,390 | 2,190 | ........ |
| 30 | [2] 280.7 | ........ | 8,110 | 2,125 | 38.7 |
| 31 | [1] 276.0 | 15.7 | 10,435 | 2,600 | 39.3 |
| Apr. 1 | 274.2 | 16.0 | 9,690 | 2,540 | 38.8 |
| Total | ........ | ........ | 97,480 | 23,015 | ........ |

[1] At 8 a. m.

[2] At 6 p. m.

TABLE IV.—*Live weights, water consumed, weights of excreta, and rectal temperatures*—Continued.

| Date. | Live weight. | Water consumed. | Weight of feces. | Weight of urine. | Rectal temperature. |
|---|---|---|---|---|---|
| *Period I V*—Continued. | | | | | |
| Steer A—Continued. | | | | | |
| Spilled in calorimeter and stall— | *Kilos.* | *Kilos.* | *Grams.* | *Grams.* | ° *C.* |
| Mar. 25 | | | | 196.2 | |
| 31 | | | 5.0 | | |
| From duct— | | | | | |
| Mar. 30 | | | 54.0 | | |
| Apr. 1 | | | 24.0 | | |
| Steer B: | | | | | |
| Mar. 16 | 193.4 | 8.2 | 4,910 | 1,505 | 38.6 |
| 17 | 193.5 | 13.5 | 5,080 | 1,870 | 38.5 |
| 18 | 197.0 | 5.7 | 7,830 | 1,840 | 38.8 |
| 19 | 193.5 | 9.3 | 6,835 | 1,575 | 38.5 |
| 20 | 194.2 | 10.0 | 5,990 | 1,310 | 38.2 |
| 21 | [1] 198.6 | 1.8 | 7,095 | 1,730 | 38.5 |
| 21 | 198.1 | | | | 38.5 |
| 22 | | | 4,910 | 1,350 | |
| 23 | [2] 182.2 | | 4,985 | 1,260 | 38.6 |
| 24 | [1] 179.4 | 20.4 | 3,830 | 1,695 | 38.6 |
| 25 | 189.9 | 11.8 | 6,730 | 1,390 | 38.4 |
| Total | | | 58,195 | 15,525 | |
| Spilled in calorimeter and stall— | | | | | |
| Mar. 23 | | | | 2,388 | |
| 24 | | | 12.0 | | |
| From duct— | | | | | |
| Mar. 23 | | | 5.8 | | |
| 25 | | | 4.8 | | |

[1] At 8 a. m.

[2] At 6 p. m.

TABLE V.—*Composition of dry matter of feces.*

| Component. | Period I. | | Period II. | | Period III. | | Period IV. | |
|---|---|---|---|---|---|---|---|---|
| | Steer A. | Steer B. | Steer A. | Steer B. | Steer A. | Steer B. | Steer A. | Steer B. |
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Ash | 7.77 | 8.77 | 8.06 | 9.45 | 5.67 | 5.87 | 5.63 | 6.50 |
| Protein[1] | 9.83 | 9.70 | 10.43 | 10.18 | 8.61 | 9.88 | 8.10 | 9.58 |
| Nonprotein[1] | | | | | | | | |
| Crude fiber | 35.47 | 35.15 | 33.60 | 34.05 | 39.94 | 38.52 | 41.08 | 39.55 |
| Nitrogen-free extract | 45.03 | 43.66 | 45.61 | 43.75 | 43.66 | 43.55 | 43.08 | 42.32 |
| Ether extract | 1.90 | 2.72 | 2.30 | 2.57 | 2.12 | 2.18 | 2.11 | 2.05 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Total nitrogen | 1.573 | 1.552 | 1.668 | 1.629 | 1.376 | 1.581 | 1.296 | 1.533 |
| Protein nitrogen | 1.200 | | | | | | | 1.093 |
| Carbon | 47.098 | 47.256 | 47.160 | 46.217 | 50.558 | 50.097 | 49.670 | 49.733 |
| Hydrogen | 5.473 | 5.662 | 5.832 | 6.747 | 5.777 | 5.890 | 6.862 | 5.702 |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Energy....per gram | 4.6141 | 4.6810 | 4.6161 | 4.5763 | 4.8606 | 4.8943 | 4.7906 | 4.8330 |

[1] Computed from nitrogen, using factors stated in Part III, page 203.

TABLE VI.—*Composition of dry matter of uneaten residues.*

| Component. | Period I—Steer B. | | | Period IV—Steer B. |
|---|---|---|---|---|
| | Jan. 24. | Jan. 26. | Jan. 25 and 26. | |
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Ash | 8.60 | 7.25 | 8.57 | 4.06 |
| NaCl | 11.86 | | | 3.30 |
| Protein[1] | 11.98 | 12.12 | 14.45 | 7.19 |
| Nonprotein[1] | 1.44 | .65 | .82 | .21 |
| Crude fiber | 13.55 | 21.22 | 17.34 | 35.02 |
| Nitrogen-free extract | 49.10 | 55.17 | 54.66 | 47.91 |
| Ether extract | 3.47 | 3.59 | 4.16 | 2.31 |
| | 100.00 | 100.00 | 100.00 | 100.00 |
| Total nitrogen | 2.222 | 2.078 | 2.487 | 1.196 |
| Protein nitrogen | 1.916 | 1.939 | 2.312 | 1.150 |
| Carbon | 39.194 | 45.705 | 45.622 | [2] 46.967 |
| Hydrogen | 6.058 | 4.842 | 6.818 | |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Energy per gram | 3.7871 | 4.4910 | 4.4645 | 4.4549 |

[1] Computed from nitrogen, using factors stated in Part III, page 203.
[2] Assumed same as hay offered.

## RESPIRATION CALORIMETER EXPERIMENTS OF 1906.

TABLE VII.—*Live weights, water consumed, weights and composition of excreta, and rectal temperatures.*

| | Live weight. | Water consumed. | Weight of feces. | Urine. | | | | Rectal temperature. |
|---|---|---|---|---|---|---|---|---|
| | | | | Weight. | Specific gravity. | Nitrogen. | | |
| | | | | | | Per cent. | Weight. | |
| *Period I.* | | | | | | | | |
| Steer A: | *Kilos.* | *Kilos.* | *Grams.* | *Grams.* | | | *Grams.* | *° C.* |
| Jan. 7 | 396.5 | 16.4 | | | | | | |
| 8 | 398.3 | 13.2 | | | | | | |
| 9 | 398.5 | 6.8 | | | | | | |
| 10 | 393.0 | 19.4 | | | | | | |
| 11 | 399.9 | 9.0 | | | | | | |
| 12 | 396.3 | 15.6 | | | | | | |
| 13 | 398.7 | 4.8 | | | | | | |
| 14 | 389.9 | 21.0 | | | | | | |
| 15 | 399.1 | 12.4 | | | | | | |
| 16 | 397.3 | 12.5 | | | | | | |
| 17 | 396.8 | 13.3 | | | | | | |
| 18 | 395.5 | 14.7 | 7,715 | 6,065 | 1.038 | 1.093 | 66.29 | 38.50 |
| 19 | 397.2 | 15.0 | 7,700 | 5,710 | 1.038 | 1.252 | 71.49 | 38.67 |
| 20 | 400.0 | 15.0 | 7,655 | 4,425 | 1.040 | 1.492 | 66.02 | 38.67 |
| 21 | 397.5 | 16.0 | 7,730 | 6,285 | 1.041 | 1.006 | 63.23 | 38.72 |
| 22 | 401.0 | 17.8 | 6,630 | 4,800 | 1.041 | 1.344 | 64.51 | 38.78 |
| 23 | 411.5 | 10.0 | 7,965 | 5,710 | 1.040 | 1.259 | 71.89 | 38.67 |
| 24 | | 8.0 | 8,115 | 5,500 | 1.039 | 1.263 | 69.49 | |
| 25 | 407.7 | 12.4 | 7,210 | 3,070 | 1.043 | 2.209 | 67.82 | 38.67 |
| 26 | 399.6 | 22.8 | 8,455 | 3,955 | 1.050 | 1.906 | 75.38 | 38.44 |
| 27 | 406.4 | 11.1 | 8,197 | 7,095 | 1.040 | 1.006 | 71.38 | 38.22 |
| Total | | | 77,372 | 52,615 | | | 687.48 | |
| Daily average | | | 7,737 | 5,262 | | 1.307 | 68.75 | 38.61 |
| Composite sample | | | | | | 1.353 | 71.19 | |
| Spilled, Jan. 21 | | | | 813.1 | | .005 | .04 | |
| 25 | | | [1] 1.0 | | | | | |
| 27 | | | | 173.5 | | 1.437 | 2.49 | |
| In duct | | | 187.8 | | | | | |
| Steer B: | | | | | | | | |
| Jan. 14 | 310.8 | .6 | | | | | | |
| 15 | 299.5 | .0 | | | | | | |
| 16 | 290.5 | 29.3 | | | | | | |
| 17 | 310.9 | 9.2 | | | | | | |
| 18 | 307.6 | 7.6 | | | | | | |
| 19 | 306.5 | 9.0 | | | | | | |

[1] Dry matter.

TABLE VII.—*Live weights, water consumed, weights and composition of excreta, and rectal temperatures*—Continued.

| | Live weight. | Water consumed. | Weight of feces. | Urine. | | | | Rectal temperature. |
|---|---|---|---|---|---|---|---|---|
| | | | | Weight. | Specific gravity. | Nitrogen. | | |
| | | | | | | Per cent. | Weight. | |
| *Period I*—Continued. | | | | | | | | |
| Steer B—Continued. | *Kilos.* | *Kilos.* | *Grams.* | *Grams.* | | | *Grams.* | ° *C.* |
| Jan. 20 | 305.0 | 10.4 | | | | | | |
| 21 | 305.0 | 10.8 | | | | | | |
| 22 | 305.0 | 10.4 | | | | | | |
| 23 | 304.4 | 0 | | | | | | |
| 24 | 295.0 | 11.5 | | | | | | |
| 25 | 298.2 | 12.4 | 5,540 | 2,670 | 1.050 | 2.001 | 53.43 | 38.44 |
| 26 | 301.4 | 8.0 | 5,935 | 3,680 | 1.052 | 1.600 | 58.88 | 38.56 |
| 27 | 298.4 | .0 | 5,165 | 4,115 | 1.045 | 1.330 | 54.73 | 38.33 |
| 28 | 290.0 | 21.8 | 4,775 | 3,335 | 1.048 | 1.553 | 51.79 | 38.44 |
| 29 | 300.9 | .0 | 6,245 | 2,413 | 1.057 | 2.163 | 52.19 | 38.44 |
| 30 | 296.2 | 15.0 | 6,095 | 2,945 | 1.060 | 2.100 | 61.85 | 38.67 |
| 31 | 301.0 | .0 | 5,325 | 3,100 | 1.051 | 1.665 | 51.62 | 38.78 |
| Feb. 1 | | 9.4 | 4,160 | 2,675 | 1.060 | 2.194 | 58.69 | |
| 2 | 301.6 | 10.6 | 7,065 | 2,160 | 1.055 | 2.409 | 52.03 | 38.89 |
| Total | | | 50,305 | 27,093 | | | 495.21 | |
| Daily average | | | 5,589 | 3,010 | | 1.828 | 55.02 | 38.56 |
| Composite sample | | | | | | 1.802 | 54.25 | |
| Spilled, Feb. 2 | | | 7.2 | | | | | |
| In duct | | | 20.0 | | | | | |
| *Period II.* | | | | | | | | |
| Steer A: | | | | | | | | |
| Feb. 9 | 420.9 | 17.4 | | | | | | |
| 10 | 415.0 | 18.5 | | | | | | 38.78 |
| 11 | 417.4 | 16.6 | | | | | | 38.89 |
| 12 | 419.2 | 19.0 | | | | | | 38.78 |
| 13 | 420.8 | 18.2 | | | | | | 39.00 |
| 14 | 418.0 | 23.8 | | | | | | 38.89 |
| 15 | 422.0 | 17.0 | 15,515 | 6,270 | 1.040 | 2.104 | 131.92 | 38.44 |
| 16 | 417.2 | 19.8 | 13,845 | 5,810 | 1.043 | 2.256 | 131.07 | 38.89 |
| 17 | 421.8 | 22.4 | 14,205 | [6,005] | [1.041] | [2.172] | [130.43] | [1]38.56 |
| 18 | 417.0 | 27.0 | 14,155 | [5,450] | [1.042] | [2.128] | [115.98] | [1]38.78 |
| 19 | 422.0 | 18.0 | 14,850 | 6,405 | 1.042 | 2.119 | 135.72 | 38.56 |
| 20 | 425.7 | 16.9 | 12,045 | 6,625 | 1.038 | 1.946 | 128.92 | 38.56 |
| 21 | | 12.7 | 13,565 | 6,025 | 1.040 | 2.240 | 134.96 | |
| 22 | 424.6 | 18.3 | 13,195 | 6,510 | 1.041 | 2.178 | 141.79 | 38.89 |
| 23 | 410.0 | 35.2 | 14,695 | 6,995 | 1.042 | 1.999 | 139.83 | 38.67 |
| 24 | 424.6 | 21.2 | 13,240 | 6,175 | 1.040 | 2.092 | 129.18 | 38.78 |
| Total | | | 139,310 | 50,815 | | | 1,073.39 | |
| Daily average | | | 13,931 | 6,352 | | 2.112 | 134.17 | 38.72 |
| Composite sample | | | | | | 2.097 | 133.20 | |
| Spilled, Feb. 15 | | | 27.5 | | | | | |
| 18 | | | 6.0 | | | | | |
| 20 | | | 33.5 | | | | | |
| 23 | | | 16.8 | | | | | |
| In duct | | | 1,193.5 | | | | | |
| Steer B: | | | | | | | | |
| Feb. 16 | 316.0 | 8.2 | | | | | | |
| 17 | 318.6 | 11.6 | | | | | | 38.33 |
| 18 | 314.0 | 16.2 | | | | | | 39.44 |
| 19 | 316.4 | .0 | | | | | | 39.72 |
| 20 | 307.8 | .0 | | | | | | 39.67 |
| 21 | 309.3 | 15.6 | | | | | | 39.33 |
| 22 | 316.1 | 8.8 | | | | | | 39.17 |
| 23 | 312.2 | 11.9 | 9,930 | 3,315 | 1.052 | 2.352 | 77.97 | 39.17 |
| 24 | 310.4 | 11.3 | 9,520 | 3,735 | 1.052 | 2.079 | 77.65 | 38.78 |
| 25 | 310.9 | 11.0 | 9,610 | 3,650 | 1.053 | 2.146 | 78.33 | 38.72 |
| 26 | 309.5 | 9.4 | 10,275 | 3,510 | 1.050 | 2.199 | 77.18 | 38.56 |
| 27 | 311.4 | 10.7 | 6,695 | 3,040 | 1.052 | 2.064 | 62.75 | 38.50 |
| 28 | | 9.7 | 9,195 | 3,920 | 1.048 | 2.072 | 81.22 | |
| Mar. 1 | 311.5 | 9.1 | 8,575 | 3,295 | 1.049 | 2.269 | 74.76 | 38.89 |
| 2 | 303.6 | 13.4 | 7,765 | 3,210 | 1.055 | 2.306 | 74.02 | 38.22 |
| 3 | 310.7 | 14.5 | 7,685 | 3,360 | 1.051 | 2.303 | 77.38 | 38.67 |
| Total | | | 79,250 | 31,035 | | | 681.26 | |
| Daily average | | | 8,806 | 3,448 | | 2.165 | 75.70 | 38.94 |
| Composite sample | | | | | | 2.165 | 74.65 | |
| Spilled, Mar. 1 | | | 10.0 | | | | | |
| In duct | | | 574.2 | | | | | |

[1] Small loss of urine on these two days. Results not included in averages.

TABLE VII.—*Live weights, water consumed, weights and composition of excreta, and rectal temperatures*—Continued.

| | Live weight. | Water consumed. | Weight of feces. | Urine. | | | | Rectal temperature. |
|---|---|---|---|---|---|---|---|---|
| | | | | Weight. | Specific gravity. | Nitrogen. Per cent. | Nitrogen. Weight. | |
| *Period III.* | | | | | | | | |
| Steer A: | *Kilos.* | *Kilos.* | *Grams.* | *Grams.* | | | *Grams.* | ° *C.* |
| Mar. 2 | 419.9 | .0 | | | | | | |
| 3 | 410.0 | 24.2 | | | | | | 37.89 |
| 4 | 421.0 | .0 | | | | | | 38.44 |
| 5 | 410.2 | .0 | | | | | | 38.33 |
| 6 | 395.6 | 25.4 | | | | | | 38.33 |
| 7 | 410.2 | .0 | | | | | | 38.39 |
| 8 | 398.6 | 27.3 | 5,530 | 5,600 | 1.031 | 0.589 | 32.98 | 38.50 |
| 9 | 408.6 | .0 | 5,695 | 5,200 | 1.030 | .676 | 35.15 | 38.89 |
| 10 | 398.8 | 9.4 | 4,535 | 5,355 | 1.031 | .640 | 34.27 | 38.06 |
| 11 | 397.2 | 18.0 | 5,840 | 6,125 | 1.029 | .572 | 35.04 | 38.22 |
| 12 | 396.2 | 10.0 | 4,705 | 5,850 | 1.030 | .539 | 31.53 | 37.83 |
| 13 | 400.3 | 13.2 | 5,870 | 5,955 | 1.029 | .541 | 32.22 | 38.00 |
| 14 | | 8.9 | 5,820 | 4,365 | 1.030 | .736 | 32.13 | |
| 15 | 404.1 | 5.3 | 5,920 | 2,665 | 1.034 | 1.117 | 29.77 | 38.67 |
| 16 | 397.0 | 12.5 | 5,570 | 2,975 | 1.040 | 1.156 | 34.39 | 38.06 |
| 17 | 397.9 | 14.4 | 5,495 | 5,715 | 1.031 | .629 | 35.95 | 37.89 |
| Total | | | 54,980 | 49,805 | | | 333.43 | |
| Daily average | | | 5,498 | 4,981 | | .669 | 33.34 | 38.28 |
| Composite sample | | | | | | .635 | 31.63 | |
| Spilled, Mar. 15 | | | 11.3 | | | | | |
| In duct | | | 39.2 | | | | | |
| In duct | | | [1] 1.0 | | | | | |
| Steer B: | | | | | | | | |
| Mar. 9 | 304.4 | .0 | | | | | | |
| 10 | 295.6 | 12.9 | | | | | | 38.33 |
| 11 | 300.0 | 11.0 | | | | | | 37.89 |
| 12 | 301.5 | 8.2 | | | | | | 38.22 |
| 13 | 299.2 | 2.9 | | | | | | 37.89 |
| 14 | 292.3 | 14.2 | | | | | | 38.11 |
| 15 | 298.2 | 6.5 | 4,165 | 2,955 | 1.035 | .940 | 27.78 | 37.78 |
| 16 | 296.3 | 11.1 | 4,065 | | | | | 38.44 |
| 17 | 298.2 | 4.3 | 5,095 | 3,585 | 1.034 | .765 | 27.43 | 37.83 |
| 18 | 293.7 | 5.4 | 4,635 | 3,285 | 1.035 | .835 | 27.43 | 37.89 |
| 19 | 291.4 | 14.7 | 4,640 | 2,895 | 1.040 | .924 | 26.75 | 38.33 |
| 20 | 301.4 | 5.3 | 4,200 | 2,265 | 1.046 | 1.172 | 26.55 | 37.78 |
| 21 | | 13.6 | 4,275 | 2.410 | 1.041 | 1.122 | 27.04 | |
| 22 | 303.1 | 6.2 | 5,530 | 2,130 | 1.039 | 1.367 | 29.12 | 38.67 |
| 23 | 296.6 | 7.4 | 5,020 | 2,585 | 1.040 | 1.073 | 27.74 | 38.50 |
| 24 | 295.4 | 9.5 | 4,920 | 3,575 | 1.035 | .761 | 27.21 | 37.56 |
| Total | | | 46,545 | 25,685 | | | 247.05 | |
| Daily average | | | 4,655 | 2,854 | | .962 | 27.45 | 38.11 |
| Composite sample | | | | | | .930 | 26.54 | |
| In duct | | | [1] 7.6 | | | | | |
| *Period IV.* | | | | | | | | |
| Steer A: | | | | | | | | |
| Mar. 23 | 398.8 | 20.7 | | | | | | |
| 24 | 404.4 | 15.7 | | | | | | 38.11 |
| 25 | 404.9 | 14.6 | | | | | | 38.17 |
| 26 | 406.9 | 13.6 | | | | | | 38.61 |
| 27 | 406.3 | 14.2 | | | | | | 38.89 |
| 28 | 404.2 | 16.8 | | | | | | 38.00 |
| 29 | 406.4 | 13.9 | 10,560 | 4,180 | 1.040 | .752 | 31.43 | 38.00 |
| 30 | 406.0 | 15.1 | 10,320 | 4,000 | 1.035 | .772 | 30.88 | 38.11 |
| 31 | 407.7 | 15.6 | 10,815 | 4,430 | 1.040 | .721 | 31.94 | 37.78 |
| Apr. 1 | 408.0 | 16.6 | 9,810 | 5,255 | 1.031 | .572 | 30.06 | 38.06 |
| 2 | 409.4 | 13.1 | 11,305 | 5,065 | 1.035 | .596 | 30.19 | 38.22 |
| 3 | 412.6 | 13.4 | 9,060 | 5,530 | 1.032 | .530 | 29.31 | 37.67 |
| 4 | | 11.2 | 11,985 | 4,400 | 1.034 | .676 | 29.74 | |
| 5 | 410.0 | 9.0 | 11,515 | 3,450 | 1.040 | .854 | 29.46 | 38.78 |
| 6 | 398.0 | 19.8 | 11,900 | 3,900 | 1.036 | .862 | 33.62 | 38.44 |
| 7 | 401.7 | 21.7 | 12,595 | 4,630 | 1.033 | .678 | 31.39 | 38.78 |
| Total | | | 109,865 | 44,840 | | | 308.02 | |
| Daily average | | | 10,987 | 4,484 | | .687 | 30.80 | 38.28 |
| Composite sample | | | | | | .690 | 30.94 | |
| In duct | | | 170.3 | | | | | |

[1] Dry matter.

TABLE VII.—*Live weights, water consumed, weights and composition of excreta, and rectal temperatures*—Continued.

| | Live weight. | Water consumed. | Weight of feces. | Urine. | | | | Rectal temperature. |
|---|---|---|---|---|---|---|---|---|
| | | | | Weight. | Specific gravity. | Nitrogen. | | |
| | | | | | | Per cent. | Weight. | |
| *Period IV—Continued.* | | | | | | | | |
| Steer B: | *Kilos.* | *Kilos.* | *Grams.* | *Grams.* | | | *Grams.* | *°C.* |
| Mar. 30 | 297.0 | 11.5 | | | | | | |
| 31 | 299.2 | 12.0 | | | | | | 37.56 |
| Apr. 1 | 302.0 | 7.0 | | | | | | 37.78 |
| 2 | 299.6 | 14.4 | | | | | | 38.67 |
| 3 | 305.5 | 10.1 | | | | | | 37.78 |
| 4 | 305.3 | 13.7 | | | | | | 38.89 |
| 5 | 307.5 | 9.5 | 7,610 | 3,380 | 1.043 | 0.922 | 31.16 | 38.06 |
| 6 | 306.4 | 8.0 | 8,565 | 3,075 | 1.045 | 1.032 | 31.73 | 37.83 |
| 7 | 303.4 | 13.8 | 7,630 | 3,275 | 1.041 | .920 | 30.13 | 37.89 |
| 8 | 307.2 | 11.4 | 8,320 | 3,240 | 1.046 | .933 | 30.23 | 37.78 |
| 9 | 308.0 | 12.7 | 8,280 | 3,955 | 1.040 | .800 | 31.64 | 38.11 |
| 10 | 312.6 | 7.0 | 8,710 | 3,215 | 1.041 | .899 | 28.90 | 37.89 |
| 11 | | 12.4 | 8,305 | 2,945 | 1.045 | 1.022 | 30.10 | |
| 12 | 313.9 | 9.8 | 8,880 | 2,800 | 1.042 | 1.004 | 28.11 | 38.56 |
| 13 | 305.0 | 11.8 | 8,835 | 3,235 | 1.044 | .910 | 29.44 | 38.78 |
| 14 | 304.8 | 12.7 | 8,250 | 3,265 | 1.046 | .909 | 29.68 | 38.67 |
| Total | | | 83,585 | 32,385 | | | 301.12 | |
| Daily average | | | 8,359 | 3,239 | | .930 | 30.11 | 38.17 |
| Composite sample | | | | | | .922 | 29.86 | |
| Spilled, Mar. 12 | | | | 157 | | .737 | | |
| 13 | | | 26.5 | | | | | |
| In duct | | | 93.7 | | | | | |

TABLE VIII.—*Composition of dry matter of feces.*

| Component and energy. | Period I. | | Period II. | | Period III. | | Period IV. | |
|---|---|---|---|---|---|---|---|---|
| | Steer A. | Steer B. | Steer A. | Steer B. | Steer A. | Steer B. | Steer A. | Steer B. |
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Ash | 9.47 | 9.08 | 8.50 | 8.61 | 6.60 | 7.71 | 7.15 | 7.45 |
| Protein[1]<br>Nonprotein[1] | 13.36 | 12.47 | 16.73 | 13.55 | 10.71 | 10.56 | 10.44 | 10.73 |
| Crude fiber | 31.15 | 32.40 | 31.95 | 34.91 | 34.61 | 32.64 | 34.86 | 33.50 |
| Nitrogen-free extract | 43.90 | 43.94 | 40.62 | 40.94 | 46.02 | 46.78 | 45.41 | 46.24 |
| Ether extract | 2.12 | 2.11 | 2.20 | 1.99 | 2.06 | 2.31 | 2.14 | 2.08 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Total nitrogen | 2.137 | 1.995 | 2.676 | 2.168 | 1.713 | 1.690 | 1.670 | 1.717 |
| Carbon | 47.77 | 48.16 | 48.10 | 47.67 | 49.14 | 49.49 | 48.86 | 49.55 |
| Hydrogen | 6.38 | 6.34 | 6.67 | 6.55 | 6.55 | 6.60 | 6.33 | 6.73 |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Energy...per gram | 4.6793 | 4.7075 | 4.6896 | 4.6307 | 4.8011 | 4.7992 | 4.7985 | 4.7940 |

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[1] Computed from nitrogen, using the factors stated in Part III, page 203.

## RESPIRATION CALORIMETER EXPERIMENTS OF 1907.

TABLE IX.—*Live weights, water consumed, weights and composition of excreta, and rectal temperatures.*

| Period. | Live weight. | Water consumed. | Weight of feces. | Urine. |  |  |  | Rectal temperature. |
|---|---|---|---|---|---|---|---|---|
|  |  |  |  | Weight. | Specific gravity. | Per cent nitrogen. | Weight of nitrogen. |  |
| *Period I.* |  |  |  |  |  |  |  |  |
| Steer A: | *Kilos.* | *Kilos.* | *Grams.* | *Grams.* |  |  | *Grams.* | ° *C.* |
| Jan. 23 | 497.6 | 1.0 |  |  |  |  |  |  |
| 24 | 483.2 | 17.4 |  |  |  |  |  | 38.89 |
| 25 | 487.6 | 16.2 |  |  |  |  |  | 38.45 |
| 26 | 493.0 | 0.0 |  |  |  |  |  | 38.00 |
| 27 | 483.2 | 24.2 |  |  |  |  |  | 37.89 |
| 28 | 497.0 | 13.2 |  |  |  |  |  | 38.22 |
| 29 | 497.6 | 8.4 |  |  |  |  |  | 38.34 |
| 30 | 493.8 | 16.8 |  |  |  |  |  | 38.00 |
| 31 | 497.8 | 13.6 | 7,385 | 3,525 | 1.047 |  |  | 38.00 |
| Feb. 1 | 500.0 | 14.6 | 9,955 | 3,750 | 1.045 |  |  | 38.00 |
| 2 | 500.0 | 14.6 | 8,090 | 4,920 | 1.040 |  |  | 38.56 |
| 3 | 500.4 | 12.2 | 7,785 | 4,535 | 1.042 |  |  | 38.22 |
| 4 | 500.0 | 15.0 | 8,410 | 4,290 | 1.041 |  |  | 38.11 |
| 5 | 504.6 | 0.0 | 7,275 | 6,110 | 1.038 |  |  | 38.00 |
| 6 |  | 15.2 | 8,955 | 3,565 | 1.049 |  |  |  |
| 7 | 498.3 | 9.8 | 8,960 | 3,495 | 1.045 |  |  | [2] 38.78 |
| 8 | 489.0 | 24.2 | 8,600 | 3,110 | 1.050 |  |  | 37.89 |
| 9 | 499.0 | 20.6 | 9,175 | 5,140 | 1.039 |  |  | 38.00 |
| Total |  |  | 84,590 | 42,440 |  |  |  |  |
| Daily average |  |  | 8,459 | 4,244 |  | 1.682 |  | 38.21 |
| Spilled Feb. 7 |  |  | 5.0 | 975 |  | .885 |  |  |
| In duct |  |  | 616.9 |  |  |  |  |  |
| Steer B: |  |  |  |  |  |  |  |  |
| Jan. 31 | 367.0 | 9.4 |  |  |  |  |  | 37.67 |
| Feb. 1 | 366.8 | 12.0 |  |  |  |  |  | 37.78 |
| 2 | 369.2 | 13.2 |  |  |  |  |  | 37.89 |
| 3 | 373.0 | .0 |  |  |  |  |  | 38.67 |
| 4 | 363.0 | 17.0 |  |  |  |  |  | 37.83 |
| 5 | 371.2 | 9.4 |  |  |  |  |  | 37.50 |
| 6 | 371.6 | 8.8 |  |  |  |  |  | 37.89 |
| 7 | 370.4 | 11.6 | 6,745 | 3,565 | 1.050 |  |  | 37.89 |
| 8 | 372.0 | .0 | 5,485 | 2,990 | 1.051 |  |  | 37.67 |
| 9 | 363.0 | 18.4 | 6,475 | 3,400 | 1.052 |  |  | 38.45 |
| 10 | 371.2 | 10.0 | 5,475 | 3,435 | 1.050 |  |  | 38.00 |
| 11 | 371.0 | 3.6 | 6,425 | 4,030 | 1.045 |  |  | 38.22 |
| 12 | [1] 368.8 | 13.4 | 5,380 | 3,095 | 1.050 |  |  | 37.56 |
| 13 |  | 6.8 | 6,850 | 2,630 | 1.054 |  |  |  |
| 14 | [2] 373.6 | 7.5 | 5,730 | 2,745 | 1.053 |  |  | [2] 39.00 |
| 15 | 365.2 | 10.4 | 6,480 | 3,005 | 1.052 |  |  | 37.78 |
| 16 | 365.8 | 12.2 | 5,905 | 3,125 | 1.044 |  |  | 37.89 |
| Total |  |  | 60,950 | 32,020 |  |  |  |  |
| Daily average |  |  | 6,095 | 3,202 |  | 1.820 |  | 37.98 |
| Spilled, Feb. 16 |  |  |  | 1,120.7 |  | .422 |  |  |
| In duct |  |  | 7.4 |  |  |  |  |  |
| *Period II.* |  |  |  |  |  |  |  |  |
| Steer A: |  |  |  |  |  |  |  |  |
| Feb. 21 | 516.6 | 21.0 |  |  |  |  |  | 38.34 |
| 22 | 518.0 | 21.6 |  |  |  |  |  | 38.67 |
| 23 | 517.8 | 21.8 |  |  |  |  |  | 38.67 |
| 24 | 519.6 | 23.0 |  |  |  |  |  | 38.78 |
| 25 | 519.4 | 21.8 |  |  |  |  |  | 38.45 |
| 26 | 517.4 | 22.8 |  |  |  |  |  | 38.78 |
| 27 | 516.4 | 21.2 |  |  |  |  |  | 38.56 |
| 28 | 519.4 | 20.8 | 12,625 | 7,395 | 1.032 | 1.924 | 142.28 | 38.34 |
| Mar. 1 | 516.4 | 27.6 | 14,570 | 7,725 | 1.031 | 1.841 | 142.22 | 38.89 |
| 2 | 519.6 | 22.4 | 14,010 | 8,770 | 1.030 | 1.705 | 149.53 | 38.78 |
| 3 | 516.6 | 30.4 | 12,310 | 10,285 | 1.030 | 1.437 | 147.80 | 38.78 |
| 4 | 521.4 | 21.2 | 14,960 | 9,285 | 1.031 | 1.669 | 154.97 | 38.78 |
| 5 | 528.0 | 17.0 | 10,815 | 7,460 | 1.033 | 1.767 | 131.82 | 38.45 |
| 6 |  | 13.5 | 15,155 | 8,645 | 1.030 | 1.847 | 159.67 |  |
| 7 | 522.0 | 21.4 | 11,905 | 7,260 | 1.034 | 2.089 | 151.66 | [2] 39.23 |
| 8 | 507.0 | 31.2 | 12,655 | 7,390 | 1.032 | 2,126 | 157.11 | 38.67 |
| 9 | 517.0 | 37.0 | 13,545 | 6,815 | 1.039 | 2.341 | 159.54 | 39.12 |
| Total |  |  | 132,550 | 81,030 |  |  | 1,496.60 |  |

[1] At 8 a. m.

[2] At 6 p. m.

TABLE IX.—*Live weights, water consumed, weights and composition of excreta, and rectal temperature*—Continued.

| Period. | Live weight. | Water consumed. | Weight of feces. | Urine. | | | | Rectal temperature. |
|---|---|---|---|---|---|---|---|---|
| | | | | Weight. | Specific gravity. | Per cent nitrogen. | Weight of nitrogen. | |
| *Period II*—Continued. | | | | | | | | |
| Steer A—Continued. | *Kilos.* | *Kilos.* | *Grams.* | *Grams.* | | | *Grams.* | ° *C.* |
| Daily average | | | 13,255 | 8,103 | | 1.847 | 149.66 | 38.71 |
| Composite sample | | | | | | 1.836 | 148.76 | |
| Spilled, Mar. 5 | | | | 270.4 | | 2.183 | | |
| Spilled, Mar. 7 | | | 142.3 | | | | | |
| In duct | | | 1,241.0 | | | | | |
| Steer B: | | | | | | | | |
| Feb. 28 | 381.4 | 12.6 | | | | | | 38.00 |
| Mar. 1 | 381.2 | 15.0 | | | | | | 38.56 |
| 2 | 381.0 | 15.4 | | | | | | 38.78 |
| 3 | 382.4 | 8.6 | | | | | | 38.56 |
| 4 | 379.0 | 17.4 | | | | | | 38.45 |
| 5 | 384.2 | 12.0 | | | | | | 38.78 |
| 6 | 384.6 | 13.8 | | | | | | 38.67 |
| 7 | 380.0 | 14.8 | 7,410 | 3,805 | 1.051 | 2.360 | 89.80 | 38.67 |
| 8 | 380.6 | 12.8 | 8,205 | 3,360 | 1.052 | 2.369 | 79.60 | 38.56 |
| 9 | 383.2 | 17.2 | 5,925 | 4,165 | 1.050 | 2.274 | 94.71 | 38.89 |
| 10 | 386.0 | 13.8 | 8,245 | 3,105 | 1.052 | 2.434 | 75.58 | 38.34 |
| 11 | 386.2 | 12.6 | 8,245 | 3,395 | 1.052 | 2.453 | 83.28 | 38.34 |
| 12 | [1] 391.2 | 7.0 | 6,920 | 4,295 | 1.050 | 2.177 | 93.50 | 38.34 |
| 13 | | 13.1 | 6,875 | 3,535 | 1.055 | 2.420 | 85.55 | |
| 14 | | 12.6 | 7,195 | 3,450 | 1.055 | 2.643 | 91.18 | [2] 38.89 |
| 15 | 380.6 | 22.4 | 7,230 | 3,270 | 1.056 | 2.571 | 84.07 | 38.78 |
| 16 | 388.0 | 18.4 | 8,445 | 5,405 | 1.045 | 1.632 | 88.21 | 37.89 |
| Total | | | 74,695 | 37,785 | | | 865.48 | |
| Daily average | | | 7,469.5 | 3,778.5 | | 2.291 | 86.55 | 38.53 |
| Composite sample | | | | | | 2.216 | 83.74 | |
| Spilled, Mar. 10 | | | | 269.6 | | 2.156 | | |
| Spilled, Mar. 14 | | | 69.3 | | | | | |
| Spilled, Mar. 15 | | | | 102.2 | | 1.250 | | |
| Spilled, Mar. 16 | | | | 173.2 | | .181 | | |
| In duct | | | 569.6 | | | | | |
| *Period III.* | | | | | | | | |
| Steer A: | | | | | | | | |
| Mar. 10 | 518.0 | 2.4 | | | | | | |
| 11 | 509.0 | 10.0 | | | | | | |
| 12 | 510.4 | 14.6 | | | | | | |
| 13 | 515.2 | 9.0 | | | | | | |
| 14 | 510.4 | 20.4 | | | | | | |
| 15 | 522.0 | 18.0 | | | | | | |
| 16 | 522.0 | 2.2 | | | | | | 38.45 |
| 17 | 513.0 | 14.4 | | | | | | 38.78 |
| 18 | 516.0 | 16.0 | | | | | | 37.89 |
| 19 | 519.4 | 9.2 | | | | | | 38.00 |
| 20 | 515.4 | 6.0 | | | | | | 37.56 |
| 21 | 509.0 | 15.2 | 5,280 | 6,100 | 1.033 | .531 | 32.39 | 37.78 |
| 22 | 510.4 | 14.8 | 5,635 | 7,135 | 1.030 | .496 | 35.39 | 38.11 |
| 23 | 510.2 | 15.8 | 5,345 | 7,620 | 1.030 | .435 | 33.15 | 38.45 |
| 24 | 509.4 | 12.8 | 5,135 | 9,350 | 1.024 | .358 | 33.47 | 37.89 |
| 25 | 509.0 | 0.0 | 4,435 | 8,080 | 1.025 | .388 | 31.35 | 37.89 |
| 26 | [3] 501.8 | 17.0 | 4,085 | | | | | 37.22 |
| 27 | | 10.7 | 5,475 | 4,480 | 1.030 | .592 | 26.52 | |
| 28 | [3] 511.0 | 5.3 | 4.170 | 2,805 | 1.035 | 1.199 | 33.63 | [2] 38.34 |
| 29 | 503.6 | 22.0 | 5,600 | 4,465 | 1.033 | .776 | 34.65 | 38.22 |
| 30 | 509.0 | 0.0 | 5,005 | 10,000 | 1.023 | .333 | 33.30 | 38.11 |
| Total | | | 50,165 | 60,035 | | | 293.85 | |
| Daily average | | | 5,016.5 | 6,670.6 | | .490 | 32.65 | 38.05 |
| Composite sample | | | | | | .479 | 31.96 | |
| Spilled, Mar. 28 | | | 64.0 | | | | | |
| In duct | | | 176.8 | | | | | |
| Washings from duct | | | 185.0 | | | | | |

[1] At 7.20 a. m.

[2] At 6 p. m.

[3] At 7.30 a. m.

TABLE IX.—*Live weights, water consumed, weights and composition of excreta, and rectal temperatures*—Continued.

| Period. | Live weight. | Water consumed. | Weight of feces. | Urine. |  |  |  | Rectal temperature. |
|---|---|---|---|---|---|---|---|---|
|  |  |  |  | Weight. | Specific gravity. | Per cent nitrogen. | Weight of nitrogen. |  |
| *Period III*—Continued. |  |  |  |  |  |  |  |  |
| Steer B: | *Kilos.* | *Kilos.* | *Grams.* | *Grams.* |  |  | *Grams.* | ° *C.* |
| Mar. 17 | 389.6 | 0.8 |  |  |  |  |  |  |
| 18 | 390.2 | 4.8 |  |  |  |  |  |  |
| 19 | 382.0 | 2.2 |  |  |  |  |  |  |
| 20 | 386.8 | 2.0 |  |  |  |  |  |  |
| 21 | 385.0 | 0.0 |  |  |  |  |  |  |
| 22 | 375.2 | 20.2 |  |  |  |  |  | 37.22 |
| 23 | 382.0 | 0.0 |  |  |  |  |  | 37.78 |
| 24 | 368.0 | 14.0 |  |  |  |  |  | 38.56 |
| 25 | 372.0 | 0.0 |  |  |  |  |  | 37.78 |
| 26 | 363.4 | 18.6 |  |  |  |  |  | 38.11 |
| 27 | 374.8 | 13.2 |  |  |  |  |  | 38.00 |
| 28 | 378.6 | 7.8 | 4.820 | 3.585 | 1.040 | .914 | 32.77 | 38.34 |
| 29 | 372.0 | 16.2 | 4.850 | 4.880 | 1.034 | .665 | 32.45 | 38.22 |
| 30 | 377.0 | 7.0 | 4,625 | 4.305 | 1.033 | .694 | 29.88 | 37.67 |
| 31 | 374.0 | 8.4 | 4,815 | 4.790 | 1.033 | .575 | 27.60 | 37.56 |
| Apr. 1 | 372.4 | 10.0 | 4.580 | 4.855 | 1.033 | .563 | 27.33 | 38.34 |
| 2 | [1] 376.4 | 0.0 | 5,435 | 3.720 | 1.040 | .617 | 22.95 | 38.34 |
| 3 |  | 13.1 | 4,530 | 2.240 | 1.050 | 1.044 | 23.39 |  |
| 4 | [2] 376.8 | 7.8 | 4,500 | 1,875 | 1.052 | 1.479 | 27.73 | [2] 38.56 |
| 5 | 368.0 | 16.0 | 5,135 | 2.700 | 1.048 | 1.091 | 29.46 | 38.11 |
| 6 | 374.4 | 14.8 | 4,495 | 6,245 | 1.032 | .486 | 30.35 | 37.67 |
| Total |  |  | 47.785 | 39.195 |  |  | 284.00 |  |
| Daily average |  |  | 4,778.5 | 3,919.5 |  | .725 | 28.40 | 38.02 |
| Composite sample |  |  |  |  |  | .717 | 28.10 |  |
| Spilled, Mar. 28 |  |  |  | 188.8 |  | .146 |  |  |
| Spilled, Mar. 28 |  |  |  | [3] 50.0 |  |  |  |  |
| Spilled, Apr. 4 |  |  | 4.2 |  |  |  |  |  |
| In duct |  |  | 73.7 |  |  |  |  |  |
| *Period IV.* |  |  |  |  |  |  |  |  |
| Steer A: |  |  |  |  |  |  |  |  |
| Mar. 31 | 493.0 | 20.0 |  |  |  |  |  |  |
| Apr. 1 | 500.8 | 10.6 |  |  |  |  |  |  |
| 2 | 499.0 | 11.8 |  |  |  |  |  |  |
| 3 | 497.0 | 15.3 |  |  |  |  |  |  |
| 4 | [4] 503.2 | 18.8 |  |  |  |  |  | 37.22 |
| 5 | 505.0 | 19.2 |  |  |  |  |  | 38.22 |
| 6 | 508.0 | 14.2 |  |  |  |  |  | 38.00 |
| 7 | 506.6 | 23.8 |  |  |  |  |  | 38.34 |
| 8 | 511.6 | 16.0 |  |  |  |  |  | 38.34 |
| 9 | 512.0 | 15.0 |  |  |  |  |  | 38.00 |
| 10 | 512.2 | 16.6 |  |  |  |  |  | 38.34 |
| 11 | 513.4 | 16.0 | 9.185 | 6.540 | 1.034 | .448 | 29.30 | 38.11 |
| 12 | 511.0 | 18.2 | 9.865 | 7.710 | 1.030 | .377 | 29.07 | 38.45 |
| 13 | 510.4 | 19.0 | 10.690 | 7,945 | 1.031 | .376 | 29.87 | 38.56 |
| 14 | 514.0 | 18.4 | 8,830 | 6,230 | 1.032 | .455 | 28.35 | 38.34 |
| 15 | 515.8 | 14.2 | 10,095 | 5.475 | 1.035 | .545 | 29.84 | 38.34 |
| 16 | [1] 518.0 | 19.4 | 10,140 | 5,785 | 1.036 | .466 | 26.96 | 38.34 |
| 17 |  | 11.8 | 9,565 | 5,955 | 1.033 | .449 | 26.74 |  |
| 18 | [2] 518.4 | 9.4 | 10,890 | 3,720 | 1.043 | .717 | 26.67 | [2] 38.67 |
| 19 | 506.2 | 25.6 | 10.370 | 4,465 | 1.045 | .632 | 28.22 | 38.56 |
| 20 | 513.0 | 12.4 | 10,025 | 7,590 | 1.035 | .412 | 31.27 | 38.00 |
| Total |  |  | 99,655 | 61.415 |  |  | 296.29 |  |
| Daily average |  |  | 9,966 | 6,142 |  | .466 | 28.63 | 38.24 |
| Composite sample |  |  |  |  |  | .457 | 28.07 |  |
| Spilled, Apr. 11 |  |  |  | 226.5 |  | .079 |  |  |
| Spilled. Apr. 18 |  |  | 27.6 |  |  |  |  |  |
| In duct |  |  | 402.5 |  |  |  |  |  |

[1] At 7.30 a. m.

[2] At 6 p. m.

[3] Estimated.

[4] At 11 a. m.

TABLE IX.—*Live weights, water consumed, weights and composition of excreta, and rectal temperatures*—Continued.

| Period. | Live weight. | Water consumed. | Weight of feces. | Urine. | | | | Rectal temperature. |
|---|---|---|---|---|---|---|---|---|
| | | | | Weight. | Specific gravity. | Per cent nitrogen. | Weight of nitrogen. | |
| *Period IV*—Continued. | | | | | | | | |
| Steer B: | *Kilos.* | *Kilos.* | *Grams.* | *Grams.* | | | *Grams.* | *° C.* |
| Apr. 7 | 371.4 | 9.0 | | | | | | |
| 8 | 370.0 | 12.0 | | | | | | |
| 9 | 373.2 | 7.4 | | | | | | |
| 10 | 373.0 | 20.4 | | | | | | |
| 11 | 380.0 | 4.2 | | | | | | 37.33 |
| 12 | 378.4 | 14.2 | | | | | | 38.56 |
| 13 | 382.0 | 9.6 | | | | | | 38.45 |
| 14 | 379.6 | 20.4 | | | | | | 39.00 |
| 15 | 384.6 | 16.6 | | | | | | 38.00 |
| 16 | 386.4 | 16.4 | | | | | | 38.45 |
| 17 | 387.6 | 16.4 | | | | | | 38.78 |
| 18 | 387.6 | 14.4 | 8,325 | 5,600 | 1.038 | .511 | 28.62 | 38.78 |
| 19 | 381.8 | 21.8 | 10,940 | 10,290 | 1.030 | .307 | 31.59 | 38.56 |
| 20 | 384.6 | 16.4 | 9,160 | 6,585 | 1.037 | .382 | 25.15 | 38.56 |
| 21 | 383.8 | 21.6 | 9,500 | 9,560 | 1.031 | .297 | 28.39 | 38.67 |
| 22 | 383.2 | 14.8 | 10.025 | 9,550 | 1.032 | .247 | 23.59 | 38.34 |
| 23 | [1] 390.0 | 4.4 | 7,835 | 3,260 | 1.050 | .756 | 24.65 | 38.45 |
| 24 | | 15.7 | 9,585 | 2,375 | 1.055 | .972 | 23.09 | |
| 25 | [2] 389.6 | 11.8 | 8,755 | | | | | [2] 38.34 |
| 26 | 379.4 | 17.6 | 7,940 | 3,510 | 1.053 | .834 | 29.27 | 38.67 |
| 27 | 383.4 | 17.6 | 10,390 | 4,495 | 1.043 | .720 | 32.36 | 38.34 |
| Total | | | 92,455 | 55.225 | | | 246.71 | |
| Daily average | | | 9,245.5 | 6,136.1 | | .447 | 27.41 | 38.46 |
| Composite sample | | | | | | .456 | 27.98 | |
| In duct | | | 18.8 | | | | | |

[1] At 7.30 a. m.

[2] At 6 p. m.

TABLE X.—*Composition of dry matter of feces.*

| Components and energy. | Period I. | | Period II. | | Period III. | | Period IV. | |
|---|---|---|---|---|---|---|---|---|
| | Steer A. | Steer B. | Steer A. | Steer B. | Steer A. | Steer B. | Steer A. | Steer B. |
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Ash | 9.67 | 9.63 | 10.39 | 10.01 | 8.03 | 8.20 | 8.21 | 7.87 |
| Protein [1] | 13.38 | 10.83 | 15.59 | 13.29 | 10.01 | 9.51 | 9.81 | 9.95 |
| Crude fiber [1] | 29.03 | 29.70 | 29.78 | 29.76 | 30.73 | 29.40 | 29.19 | 29.51 |
| Nitrogen-free extract | 45.57 | 47.07 | 42.05 | 44.42 | 48.30 | 49.84 | 49.88 | 49.93 |
| Ether extract | 2.35 | 2.77 | 2.19 | 2.52 | 2.93 | 3.05 | 2.91 | 2.74 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Total nitrogen | 2.141 | 1.733 | 2.495 | 2.127 | 1.601 | 1.521 | 1.570 | 1.592 |
| Carbon | 48.508 | 48.361 | 47.598 | 47.811 | 49.629 | 49.685 | 49.597 | 49.351 |
| Hydrogen | 5.674 | 5.748 | 5.644 | 5.478 | 5.883 | 5.722 | 5.799 | 5.714 |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Energy....per gram | 4.7596 | 4.7967 | 4.6905 | 4.7787 | 4.9232 | 4.9388 | 4.9166 | 4.9279 |

[1] Computed from nitrogen, using the factors stated in Part III, page 203.

## DIGESTION AND METABOLISM TRIALS DURING INTERMEDIATE PERIODS.

TABLE XI.—*Live weights, water consumed, and weights and composition of excreta.*

| Date. | Live weight. | Water consumed. | Fresh weight of feces. | Urine. | | | |
|---|---|---|---|---|---|---|---|
| | | | | Weight. | Specific gravity. | Nitrogen. | |
| | | | | | | Per cent. | Weight. |
| *Nov. 28 to Dec. 10, 1904.* | | | | | | | |
| **Steer A:** | *Kilos.* | *Kilos.* | *Grams.* | *Grams.* | | | *Grams.* |
| Nov. 28 | 273.6 | | | | | | |
| 29 | 275.0 | | | | | | |
| 30 | 260.0 | | | | | | |
| Dec. 1 | 270.4 | 20.2 | 6,385 | 3,310 | | | |
| 2 | 273.6 | 14.1 | 6,560 | 3,690 | | | |
| 3 | 270.9 | 22.3 | 7,475 | | | | |
| 4 | 278.1 | 18.9 | 10,790 | 6,275 | | | |
| 5 | 282.4 | 14.4 | 8,990 | 5,810 | | | |
| 6 | 279.5 | 16.4 | 8,505 | 5,425 | | | |
| 7 | 280.8 | 19.1 | 8,830 | 5,825 | | | |
| 8 | 284.5 | 12.7 | 8,115 | 4,830 | | | |
| 9 | 279.0 | 20.5 | 8,030 | 6,500 | | | |
| 10 | 283.6 | 20.5 | 10,040 | 7,410 | | | |
| Total | | | 83,720 | 49,075 | | | |
| Daily average | | | 8,372 | 5,453 | | 1.440 | 78.52 |
| In duct | | | 980 | | | | |
| **Steer B:** | | | | | | | |
| Nov. 28 | 191.8 | | | | | | |
| 29 | 208.6 | | | | | | |
| 30 | 208.2 | | | | | | |
| Dec. 1 | 207.2 | 15.0 | 7,165 | 3.740 | | | |
| 2 | 207.5 | 20.0 | 6,640 | 3,840 | | | |
| 3 | 211.8 | 17.9 | 8,090 | 4,120 | | | |
| 4 | 217.2 | 18.6 | 8,630 | 6,540 | | | |
| 5 | 220.4 | 13.2 | 8,225 | 5,300 | | | |
| 6 | 218.1 | 15.9 | 9,640 | 5,930 | | | |
| 7 | 218.8 | 15.5 | 8,250 | 5,850 | | | |
| 8 | 217.2 | 13.2 | 7,925 | 6,050 | | | |
| 9 | 216.3 | 16.2 | 6,975 | 5,460 | | | |
| 10 | 220.4 | 11.4 | 8,110 | 5,220 | | | |
| Total | | | 79,650 | 52.050 | | | |
| Daily average | | | 7,965 | 5,205 | | 1.340 | 69.75 |
| In duct | | | 535 | | | | |
| *June 30 to July 15, 1905.* | | | | | | | |
| **Steer A:** | | | | | | | |
| June 30 | 317.6 | 15.4 | | | | | |
| July 1 | 315.0 | 15.0 | 7,850 | [1] 5,120 | No samples taken. | | |
| 2 | 311.0 | 17.5 | 8,920 | [1] 5,470 | | | |
| 3 | 310.0 | 18.5 | 9,585 | 6,410 | | | |
| 4 | 309.5 | 21.0 | 9,180 | 6,380 | | | |
| 5 | 310.5 | 18.0 | 8,675 | [1] 7,350 | | | |
| 6 | 309.0 | 21.5 | 8,205 | [7,420] | Some urine lost. No samples of urine taken. | | |
| 7 | 309.0 | 19.5 | 8,170 | 9.670 | | | |
| 8 | 310.0 | 23.0 | 6,665 | 7,740 | | | |
| 9 | 312.0 | 21.5 | 8,130 | 10,130 | | | |
| 10 | 311.0 | 22.5 | 8,730 | 10,300 | | | |
| 11 | 313.0 | 22.0 | | [9,030] | Some urine lost. No samples of feces or urine taken. | | |
| 12 | 314.5 | 17.0 | 7,960 | 8.660 | | | |
| 13 | 314.0 | 18.5 | 7,900 | 6,525 | | | |
| 14 | 315.0 | 18.0 | 7,825 | 7,580 | | | |
| 15 | 315.0 | 20.0 | 9,410 | 6,230 | | | |
| Total | | | 72,995 | 66.835 | | | |
| Daily average | | | 8,111 | 8,604 | | .947 | 79.12 |
| In duct, July 7 | | | [2] 30 | | | | |
| In duct, July 15 | | | [2] 80 | | | | |

[1] Some loss.

[2] Dry matter.

**Table** XI.—*Live weights, water consumed, and weights and composition of excreta*—Continued.

| Date. | Live weight. | Water consumed. | Fresh weight of feces. | Urine. | | | |
|---|---|---|---|---|---|---|---|
| | | | | Weight. | Specific gravity. | Nitrogen. | |
| | | | | | | Per cent. | Weight. |
| *June 30 to July 15, 1905*—Con. | | | | | | | |
| **Steer B:** | *Kilos.* | *Kilos.* | *Grams.* | *Grams.* | | | *Grams.* |
| June 30 | 230.0 | 12.4 | | | | | |
| July 1 | 230.7 | 11.7 | 6,630 | 3,110 | No samples taken. | | |
| 2 | 228.0 | 13.4 | | 3,410 | | | |
| 3 | 229.0 | 12.0 | 8,105 | 3,130 | | | |
| 4 | 227.5 | 18.0 | 7,915 | 3,120 | | | |
| 5 | 231.0 | 11.0 | 7,615 | 4,385 | | | |
| 6 | 229.0 | 16.0 | 7,855 | 3,170 | | | |
| 7 | 231.5 | 12.5 | 6,290 | 3,775 | | | |
| 8 | 231.0 | 14.0 | 7,490 | 3,700 | | | |
| 9 | 231.5 | 13.5 | 7,285 | 3,445 | | | |
| 10 | 233.0 | 17.0 | 7,015 | 3,545 | No sample of urine taken. | | |
| 11 | 234.0 | 12.5 | 8,150 | 4,415 | | | |
| 12 | 231.5 | 13.5 | 7,930 | 4,030 | | | |
| 13 | 233.0 | 16.5 | 5,915 | 3,185 | | | |
| 14 | 235.5 | 11.0 | 7,610 | 4,365 | | | |
| 15 | 234.0 | 12.5 | 7,560 | 3,580 | | | |
| Total | | | 73,100 | 37,210 | | 1.761 | 655.26 |
| Daily average | | | 7,310 | 3,721 | | | |
| In duct | | | [1] 68 | | | | |
| Urine spilled, July 9 | | | | 2,311 | | .161 | 3.72 |
| Daily average | | | | | | | 65.90 |
| *Nov. 7 to 22, 1905.* | | | | | | | |
| **Steer A:** | | | | | | | |
| Nov. 7 | 369.4 | 19.2 | | | | | |
| 8 | 368.4 | 20.0 | 11,985 | 3,780 | | | |
| 9 | 369.2 | 17.7 | 13,640 | 3,465 | | | |
| 10 | 368.4 | 20.0 | 13,125 | 3,850 | No samples taken. | | |
| 11 | 370.4 | 21.0 | 12,595 | 3,850 | | | |
| 12 | 370.9 | 16.0 | 11,535 | 3,870 | | | |
| 13 | 371.9 | 21.5 | 10,245 | 4,105 | 1.045 | | |
| 14 | 379.9 | 11.7 | 10,945 | 4,005 | 1.040 | | |
| 15 | 377.4 | 18.0 | 10,410 | 3,720 | 1.043 | | |
| 16 | 377.4 | 19.0 | 11,340 | [3,940] | | Urine not sampled nor included in computation on account of small loss. | |
| 17 | 381.9 | 15.5 | 9,240 | 4,275 | 1.041 | No sample of feces. | |
| 18 | 378.9 | 16.5 | 10,965 | 4,810 | 1.040 | | |
| 19 | 380.4 | 17.0 | 9,455 | 4,350 | 1.040 | | |
| 20 | 380.9 | 16.5 | 10,425 | 4,720 | 1.048 | | |
| 21 | 381.4 | 16.5 | 10,910 | 4,925 | 1.041 | | |
| 22 | 382.4 | 17.2 | 9,235 | 5,010 | 1.040 | | |
| Total | | | 103,170 | 39,920 | | | |
| Daily average | | | 10,317 | 4,436 | | 1.916 | 84.98 |
| From duct | | | [1] 135 | | | | |
| **Steer B:** | | | | | | | |
| Nov. 7 | 286.9 | | | | | | |
| 8 | 275.5 | 29.8 | 6,740 | 3,610 | No samples taken. | | |
| 9 | 290.8 | 7.0 | 8,605 | 3,290 | | | |
| 10 | 283.8 | 13.5 | 11,140 | 3,080 | | | |
| 11 | 283.3 | 13.0 | 9,920 | 3,905 | | | |
| 12 | 281.8 | 15.0 | 8,070 | 3,820 | | | |
| 13 | 283.8 | 12.5 | 7,920 | 3,655 | 1.050 | | |
| 14 | 285.3 | 14.0 | 8,095 | 3,035 | 1.052 | | |
| 15 | 287.3 | 14.5 | 8,470 | 3,315 | 1.050 | | |
| 16 | 288.3 | 13.0 | 9,405 | 3,730 | 1.045 | Feces not sampled. | |
| 17 | 287.3 | 13.5 | 6,940 | 4,040 | 1.044 | | |
| 18 | 287.3 | 16.0 | 8,380 | 3,950 | 1.044 | | |
| 19 | 289.8 | 14.5 | 7,660 | 4,215 | 1.040 | | |
| 20 | 290.8 | 13.0 | 8,640 | 3,955 | 1.046 | | |
| 21 | 290.3 | 13.4 | 8,225 | 4,525 | 1.042 | | |
| 22 | 289.8 | 15.2 | 8,785 | 3,965 | 1.048 | | |
| Total | | | 75,580 | 38,385 | | | |
| Daily average | | | 8,398 | 3,839 | | 1.886 | 72.39 |
| From duct | | | [1] 55.5 | | | | |

---

[1] Dry matter.

**Table XI.**—*Live weights, water consumed, and weights and composition of excreta*—Continued.

| Date. | Live weight. | Water consumed. | Fresh weight of feces. | Urine. | | | |
|---|---|---|---|---|---|---|---|
| | | | | Weight. | Specific gravity. | Nitrogen. | |
| | | | | | | Per cent. | Weight. |
| *June 19 to July 6, 1906.* | | | | | | | |
| **Steer A:** | *Kilos.* | *Kilos.* | *Grams.* | *Grams.* | | | *Grams.* |
| June 19 | 456.0 | 25.2 | | | | | |
| 20 | 453.0 | 25.4 | | | | | |
| 21 | 453.8 | 27.6 | | | | | |
| 22 | 453.0 | 25.4 | | | | | |
| 23 | 458.0 | 21.0 | | | | | |
| 24 | 455.6 | 25.4 | | | | | |
| 25 | 459.6 | 15.6 | | | | | |
| 26 | 450.4 | 23.6 | | | | | |
| 27 | 451.0 | 28.4 | 14,586 | [1] 5,475 | 1.045 | 1.696 | 92.86 |
| 28 | 454.6 | 24.8 | 15,695 | 5,400 | 1.045 | 1.647 | 88.94 |
| 29 | 451.4 | 0.0 | 18,430 | | | | |
| 30 | 429.0 | 40.0 | 10,205 | 5,860 | 1.048 | 1.482 | 86.85 |
| July 1 | 447.4 | 32.2 | 11,510 | 5,320 | 1.045 | 1.872 | 99.59 |
| 2 | 450.4 | 36.6 | 17,355 | 5,015 | 1.048 | 2.043 | 102.46 |
| 3 | 457.8 | 32.4 | 18,270 | 4,900 | 1.042 | 2.243 | 109.91 |
| 4 | 457.2 | 31.0 | 20,565 | 5,710 | 1.040 | 1.926 | 109.97 |
| 5 | 458.6 | 31.8 | 18,770 | 5,385 | 1.042 | 1.923 | 103.55 |
| 6 | 456.3 | 33.7 | 22,120 | 5,930 | 1.042 | 1.745 | 103.48 |
| Total | | | 167,505 | 48,795 | | | 897.61 |
| Daily average | | | 16,751 | 5,422 | | 1.840 | 99.73 |
| Composite sample | | | | | | 1.818 | 98.57 |
| From duct | | | 1,913 | | | | |
| **Steer B:** | | | | | | | |
| June 19 | 338.4 | 12.4 | | | | | |
| 20 | 331.0 | 24.0 | | | | | |
| 21 | 340.2 | 14.2 | | | | | |
| 22 | 335.0 | 16.0 | | | | | |
| 23 | 335.2 | 16.8 | | | | | |
| 24 | 340.0 | 8.4 | | | | | |
| 25 | 334.0 | 18.6 | | | | | |
| 26 | 336.0 | 21.6 | | | | | |
| 27 | 338.4 | 16.4 | 9,735 | 4,545 | 1.049 | 1.674 | 76.08 |
| 28 | 336.2 | 21.8 | 9,645 | 4,355 | 1.051 | 1.642 | 71.51 |
| 29 | 339.2 | 18.8 | 9,220 | 4,440 | 1.050 | 1.720 | 76.37 |
| 30 | 337.4 | 23.6 | 9,125 | 4,430 | 1.050 | 1.703 | 75.44 |
| July 1 | 342.2 | 22.4 | 9,065 | 4,485 | 1.050 | 1.805 | 80.95 |
| 2 | 344.8 | 18.8 | 9,990 | 4,360 | 1.050 | 1.850 | 80.66 |
| 3 | 343.2 | 17.0 | 9,830 | 4,635 | 1.043 | 1.768 | 81.95 |
| 4 | 343.0 | 19.0 | 9,430 | 4,635 | 1.048 | 1.738 | 80.56 |
| 5 | 342.6 | 19.0 | 8,800 | 4,810 | 1.050 | 1.604 | 77.15 |
| 6 | 342.0 | 18.4 | 9,205 | | | | |
| Total | | | 94,045 | 40,695 | | | 700.66 |
| Daily average | | | 9,405 | 4,522 | | 1.722 | 77.85 |
| Composite sample | | | | | | 1.708 | 77.24 |
| From duct | | | 934 | | | | |

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[1] Includes estimated loss of 200 grams.

TABLE XII.—*Composition of dry matter of feces.*

| Component and energy. | Dec. 1 to 10, 1904. | | June 30 to July 15, 1905. | | Nov. 7 to 22, 1905. | | June 19 to July 6, 1906. | |
|---|---|---|---|---|---|---|---|---|
| | Steer A. | Steer B. | Steer A. | Steer B. | Steer A. | Steer B. | Steer A. | Steer B. |
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Ash | 9.86 | 9.91 | 9.66 | 9.66 | 10.11 | 10.20 | 9.27 | 9.63 |
| Protein<br>Nonprotein | 17.94 | 16.38 | 17.03 | 19.98 | 14.84 | 13.70 | 16.77 | 14.92 |
| Crude fiber | 28.94 | 30.49 | 33.84 | 31.51 | 26.42 | 29.14 | 31.24 | 31.00 |
| Nitrogen-free extract | 39.27 | 39.67 | 36.50 | 35.84 | 46.37 | 44.65 | 40.41 | 41.84 |
| Ether extract | 3.99 | 3.55 | 2.97 | 3.05 | 2.26 | 2.31 | 2.31 | 2.61 |
| | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Total nitrogen | 2.87 | 2.62 | 2.725 | 3.197 | 2.374 | 2.192 | 2.683 | 2.387 |
| Protein nitrogen | ........ | ........ | 2.450 | 2.340 | 1.859 | 1.776 | 2.220 | 2.125 |
| | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| Energy....per gram | [1][4.7201] | [1][4.7201] | 4.7778 | 4.7929 | 4.6565 | 4.6495 | 4.6799 | 4.7639 |

Average of the other 3 periods.

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# CATTLE BREEDERS' ASSOCIATIONS IN DENMARK.

BY

FREDERIK RASMUSSEN,
*Professor of Dairying, New Hampshire College of Agriculture and Mechanic Arts.*

WASHINGTON:
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*Editor:* James M. Pickens.

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L. A. Rogers, *in charge of Research Laboratories.*
George M. Whitaker, *in charge of Market Milk Investigations.*
Robert McAdam, *in charge of Renovated Butter Inspection.*

# LETTER OF TRANSMITTAL.

United States Department of Agriculture,
Bureau of Animal Industry,
*Washington, D. C., September 28, 1910.*

Sir: I have the honor to transmit herewith a manuscript relating to the cattle breeders' associations and the dairy industry in Denmark, by Frederik Rasmussen, professor of dairying at the New Hampshire College of Agriculture and Mechanic Arts. The paper was written as a result of a personal visit to Denmark, together with the consultation of official reports and with cattle experts in that country.

The highly specialized nature of the dairy industry in Denmark, as well as its undoubted success, as evidenced by the high appreciation of Danish products on the British market, are well known. Although it may not be practicable or desirable in this country to follow in all respects the Danish plan and methods of organization, some of the features can probably be advantageously applied, with or without modification, to our conditions, and the information contained in the paper will undoubtedly be of value to our dairymen and to others who may be interested. I therefore respectfully recommend the publication of the article in the bulletin series of this Bureau.

Respectfully,

A. D. Melvin,
*Chief of Bureau.*

Hon. James Wilson,
*Secretary of Agriculture.*

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# CATTLE BREEDERS' ASSOCIATIONS IN DENMARK.

## BRIEF HISTORY OF THE DANISH CATTLE INDUSTRY.

During the first half of the nineteenth century Denmark was a grain-producing country. Agricultural success was measured by the raising of crops from a soil still rich in natural fertility. This for awhile was made possible by better drainage, by a rotation of crops, by treating the soil with lime or marl, and by the use of improved agricultural implements. However, it was inevitable that a system of farming in which no efforts were made to retain or add to the fertility of the soil would sooner or later become unprofitable. The live-stock industry at this time was of secondary importance. Although a few cattle were kept on nearly every farm, they received very little attention. They were pastured in summer, and as it was thought unprofitable to feed grain the stock was fed in the winter time entirely on hay and straw, especially the latter. Such treatment was very detrimental to young animals, and as in addition no systematic method of breeding was carried out, the type of cattle was retrograding instead of improving.

Later on, when it became manifest that owing to the lack of farm manure the soil was being gradually deprived of its fertility and its power to produce profitable crops, the live-stock industry began to grow in importance. The local conditions favored its development along two lines. In the main portion of Jutland the beef industry first became of greatest importance, while on the islands—Funen, Zealand, and others—the effort was directed toward the production of dairy products.

Prior to 1850 the general method in use to dispose of cattle in Jutland was to sell the steers as feeders when from 4 to 7 years old, to be fattened on the marshes along the coast of Holstein. In the year 1864 a permanent direct steamship line was established between Jutland and England, and instead of selling the steers as feeders they were fattened on the large Danish farms. The increased demand for beef at higher prices started considerable importation of Shorthorn cattle from England, to be crossed with the native stock for development of better beef qualities. The first cross was very promising, the result being a better beef form, as well as earlier maturity. But when the farmers began indiscriminately to mate cross-bred animals of second and third generations and at the same time did not fulfill the requirements in the way of feed and care demanded by the Shorthorns, a retrogression instead of an improvement was the result. The danger of this method of breeding was soon realized by some of the leading agriculturists. They also began to realize that the Jutland cattle, when properly fed and cared for, had good qualities which formerly had been overlooked, and in some places the Jutland breed was kept pure. In 1881 definite steps were taken to preserve this breed by appointing a live-stock commission for its preservation and improvement.

The importation of Shorthorn cattle had an important effect on the development of the cattle industry in Denmark, not so much by an infusion of blood, but by giving the farmers an ideal as to form and teaching them the importance of good feed and care in the rearing of cattle.

The English market demanded butter as well as beef, and after a time this had its influence on the development of the Jutland cattle. Although the beef qualities at first were considered of greatest importance, stress was afterwards laid on the milking qualities and for a time efforts were directed toward the development of a dual-purpose breed. As it proved to be difficult, if not impossible, to fix both the milk and beef producing tendencies in the animals so that both could be transmitted with certainty, this effort was abandoned. However, many people began to consider the milking qualities in the animal of greater importance than the beef qualities, and steps were taken to develop the Jutland cow as a dairy animal. But the majority of people continued to breed for beef, as is shown by the steady increase in the importation of Shorthorn cattle until about 1876, the result of which has already been discussed.

In 1860 the first "dairy counselor" was appointed by the Royal Danish Agricultural Society, and the time from 1860 to 1880 marks the period of transition from beef to milk production. During this period the main topic for discussion in the agricultural press and at meetings was the relative profit in the production of beef and butter. The profits in these two systems were often expressed by comparing the cost at which the manure was obtained. For instance, a report from Gjedsergaard in 1865 showed that where dairying was carried on the cost of the manure represented only 2.5 per cent of the value of the feed consumed (the cows being fed liberally), while in the case of feeding for beef it represented 14 per cent. This statement also illustrates that the manure was considered a very important factor in connection with the cattle industry and that the farmers fully realized the value and necessity of the manure in the production of crops on a worn-out soil.

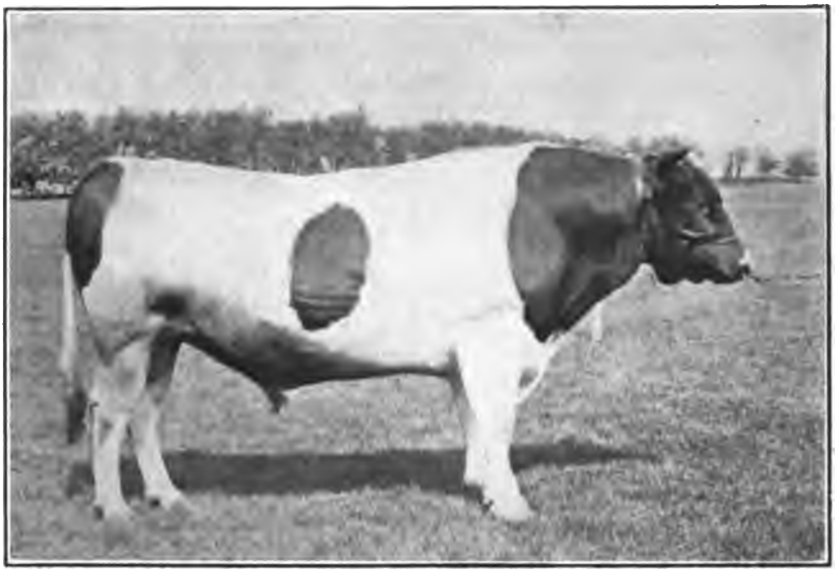

FIG. 1.—BULL, ELKJAER HOVDING, 4½ YEARS OLD. HERDBOOK NO. 1442.

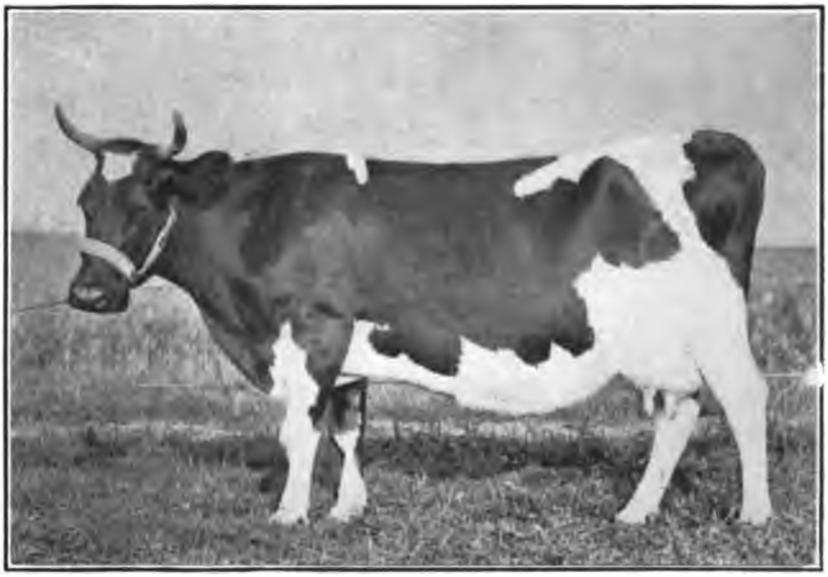

FIG. 2.—COW, HERDBOOK NO. 55.

JUTLAND BREED OF CATTLE.

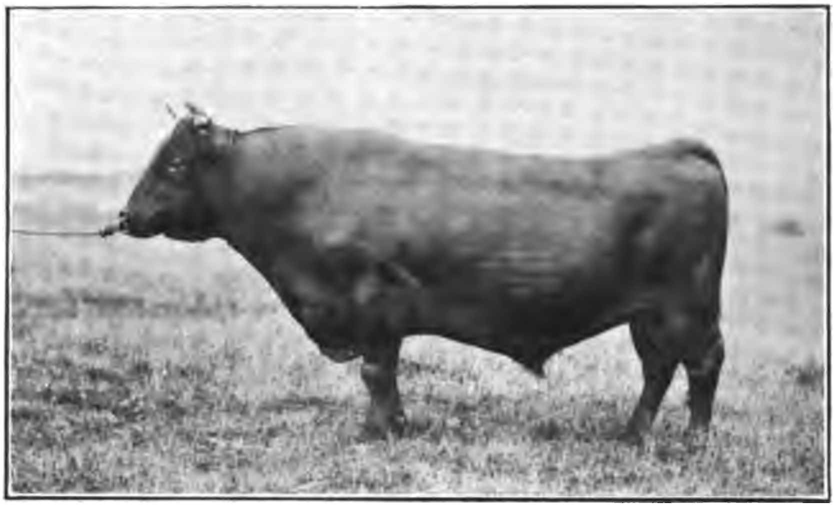

FIG. 1.—KNUD LOMBJERGE, BULL, HERDBOOK NO. 16.

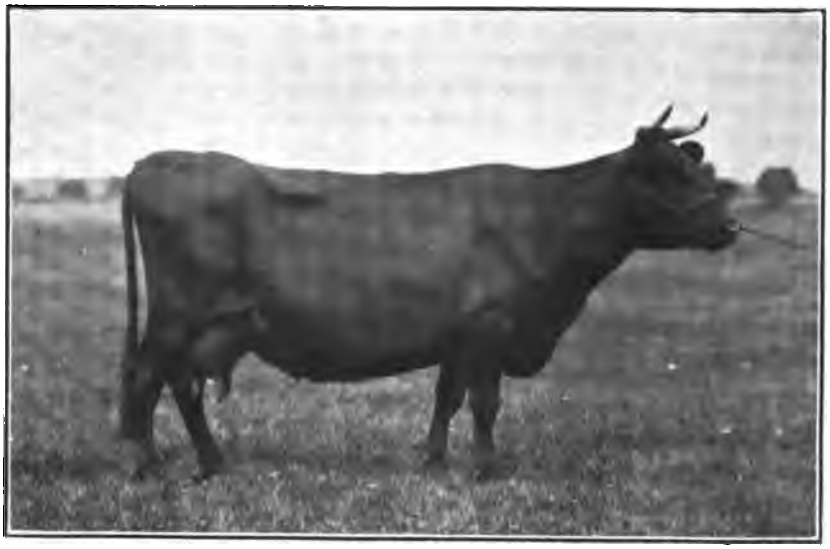

FIG. 2.—COW, HERDBOOK NO. 229.

RED DANISH CATTLE.

Although the period from 1850 to 1880 shows a marked improvement in the cattle industry in Denmark, this was due to better methods of feeding rather than to a systematic application of the principles of breeding. There were very few farmers who understood the importance of the bull in the improvement of the breed, and the nearest and cheapest bull was, as a rule, considered the best. In some sections the farmers took turns in keeping what was called the " town bull," each man keeping a bull for the use of his neighbors for a year. These bulls seldom reached an age of over 2 years, and were thus disposed of before they were fully developed and before their breeding value had been determined. More care was taken in the selection of the heifer calves for breeding purposes; they as a rule were selected from what were supposed to be the best cows; but in regard to milk production this was simply a chance selection, for very few people kept records.

## THE NATIVE BREEDS OF CATTLE IN DENMARK.

The Jutland breed has already been referred to as being native to the mainland of Denmark. The other native breed, the Red Danish, is indigenous to the islands. The cattle in Jutland were in earlier days known for their beef qualities, especially the excellent quality of meat they produced, while the cattle on the islands had superior milking qualities.

The characteristic color of the Jutland breed is black and white, a few, however, being gray and white. (See Pl. I, figs. 1 and 2.) Although the color and to some extent the general appearance would indicate the breed to contain some Holstein-Friesian blood, no historical references could be found by the writer to that effect. The origin of the breed seems unknown, and, as one writer states, it is " native to the soil." In the period from 1820 to 1850 efforts were made to improve the Jutland cattle by an infusion of new blood, and animals were imported from Tyrol, Switzerland, England, and Holstein (those from the latter place were not the Holstein-Friesian breed, but a red breed of cattle). However, this crossing did not result in an improvement of the Jutland cattle and was therefore discontinued.

The Red Danish cattle (Pl. II, figs. 1 and 2) are found in southern Jutland and on the islands of Funen, Zealand, and some of the smaller islands. The native stock which forms the basis for the Red Danish breed is different from the native stock from which the Jutland breed originated. As the name indicates, the color of the cattle is red. At the time when efforts were made to cross the native cattle of Jutland with the cattle from Tyrol and Switzerland similar attempts were made to use these breeds to improve the native stock on the islands. Furthermore, at this time cattle were also imported to the islands from Scotland (Ayrshire) and Schleswig. Most of these imported breeds, however, have had very little influence upon the development of the Red Danish cattle. The Red Danish cow may be said to be a cross between the native stock of the islands and the Angler (from Angeln in Schleswig) and other strains of cattle imported from Schleswig. The climatic condition of the islands and of Schleswig are practically the same. The imported cattle, although in several respects resembling the native stock on the islands, had superior milking qualities, but were hardly as rugged in constitution. The result of this crossing has been the development of a new and better breed.

## ORGANIZATION OF CATTLE BREEDERS' ASSOCIATIONS.

The first cattle breeders' association was formed in 1874. The object of this association was to keep pure and improve the Jutland breed by the use of purebred bulls. Eleven purebred bulls were bought and placed on different farms in the community. Few of the farmers, however, fully realized the value of the purebred bull in improving the herd; others expected greater results than could be accomplished in the course of two or three years, while the Government, although encouraging the movement, made no special provision for the aid or support of such organizations. Under these conditions probably the worst mistake made was to start the association on so large a scale; that is, with too large a territory, too large a membership, and too many bulls under one management. The farmers were not in close enough contact with one another, and it was a difficult task for the management to suit all the members in buying and placing the bulls as well as in other work which necessarily had to be left in the hands of a few. The result was that the farmers gradually lost interest in the work, and the association was dissolved in 1878. One of the principal reasons for the success of the smaller associations, as started later, is that the members are in closer contact with each other, giving frequent opportunities for discussing the work, and also that a greater number of them have an active part in the work of the association, thus securing recognition and assuming responsibility, which are two very important factors in bringing out the best results.

In 1881 a second association was formed. In this association the selection of bulls was made of more importance than previously, as shown by a paragraph in the by-laws pledging the members to use on all cows from which calves were to be reared only such bulls as had been passed on by a judging committee.

The increase in the number of associations was slow until 1887, after which rapid progress took place in all parts of the country. About 1889 the associations in some localities began to combine under one management, the object being to foster cooperation between the local and the state agricultural organizations and to get a state representative for the cattle breeders' associations. Soon after, some of the agricultural societies offered to join forces with the joint cattle breeders' association, and a common representative management was agreed upon. An expert agricultural counselor was, as a rule, appointed by the joint associations, who also frequently acted as secretary for the organization.

There were 1,095 cattle breeders' associations in operation in 1906, owning 1,369 bulls and having a total membership of 26,200. All of these associations received government aid. In addition there were at least 30 more in operation which did not receive any assistance from the Government.

### COW-TEST ASSOCIATIONS.

The minutes of a meeting of cattle breeders' associations in the district of Kolding in 1894 states that discussions took place in regard to having regular fat determinations made of each individual cow's milk to aid in the selection of good breeding animals. However, no definite steps were taken to carry out this work, and in 1895 the first cow-test association was formed in Vejen, largely through the efforts of members of the cattle breeders' associations. A rapid increase in cow-test associations followed, and it soon became evident that these associations made it unnecessary for the testing of cows to be taken up as part of the work of the cattle breeders' associations. In fact, the records of the cow-test associations became the foundation and guide for the work of the cattle breeders' associations, and it was natural that the former soon were drawn under the common management which already existed for the cattle breeders' associations and the agricultural societies.

### DUTIES OF EXPERT COUNSELOR.

As has been stated, these common-management organizations employed an expert counselor. The following rules, quoted below, laid down by the common management for the district of Kolding, will make clearer the scope of his work:

1. It is the duty of the expert to work for the advancement of the cattle breeders and the test associations under the common management:

(*a*) By taking part in meetings and fairs.

(*b*) By assisting in the selection of cows for the various cattle breeders' associations.

(*c*) By giving lectures as arranged with the presidents of the official associations.

(*d*) By attending state and other shows considered of importance in connection with his work.

(*e*) By assisting in the organization of cow-test associations, and, when necessary, helping the associations in making out yearly reports.

(*f*) By assisting the individual members in the association as much as time permits.

(*g*) By taking charge of the keeping of herd books for herds under the common management, after arrangement with its committee.

2. The expert works under the direction of the president of the common management, discussing with him the details of the work. It is his duty in every way to further the development of the cattle breeders' association and cow-test associations. He also receives information from breeders within as well as outside the district of the common management in regard to bulls of good breeding that are for sale, enabling him to direct prospective buyers. But the expert must in no way have personal financial interest in the sale of breeding animals.

3. It is also the duty of the expert to assist the agricultural societies in arranging catalogues for fairs and similar work.

4. Each year, before May 1, the expert gives a written report of his work for the past year.

## WORKING DETAILS OF CATTLE BREEDERS' ASSOCIATIONS.

Owing to the necessity of first describing the general character of the cattle breeders' associations and the gradual changes and broadening of the movement, little has been said so far in regard to the details of the work and the aim of these associations. They are local organizations, with a membership of from 4 to 60, the average being about 24. The aim of the organization is to produce a rapid improvement and development of the cattle in the community by the purchase of one or more bulls of recognized breeding. As the members of the association generally own more cows than this bull or bulls can serve, a local judging committee is appointed, which, together with the expert employed by the common-management association, visits each member and selects a number of cows worthy to be bred to the association bulls, in proportion to the size of his herd and the total number of cows in the association.

The bull is, as a rule, stationed with the member who submits the lowest bid for keeping him, the price varying from 200 kroner ($53.60) to 335 kroner ($89.78) per year.[a]

Further improvement in the cattle is to be obtained by periodical inspection of the herds, by advice in regard to the rearing of young stock, by compulsory exhibiting at association shows, and by taking part in county and government shows.

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[a] One krone=26.8 cents in United States money, which makes $1=3.73 kroner. In the remainder of this bulletin only the American equivalents of stated sums are given, except in the Appendix, consisting of quotations from Danish documents, where the Danish amounts are shown as well.

The by-laws of the associations under common management for the island of Funen, given in the Appendix, are the result of the experience in this work up to the present time. They explain several details of the work of the association and show the thoroughness of the organization. Although these laws govern only a certain district, yet those of other districts in the country for both the Jutland and the Red Danish breeds of cattle are almost identical, so they can be taken as representative of those for the whole of Denmark.

### METHOD OF FINANCING AN ASSOCIATION.

The principal items of expense in starting an association are the cost of the bull and the necessary books and blanks for keeping records. To cover these expenses a loan is obtained, for which each member is responsible in proportion to the number of cows he has registered in the association. In this way the individual members do not have to furnish the necessary funds for starting the enterprise, and thus it is possible for farmers with small means to participate. To protect the association from losses which might be incurred by accident, sickness, or death, valuable bulls are, as a rule, insured in special cooperative insurance companies.

The revenue for the maintenance of the association is derived from membership fees, service fees of the bull, the government aid, which averages $40.20 per annum for each bull belonging to the association, and the income from premiums at fairs and shows.

### GOVERNMENT AID AND SUPERVISION.

Government aid and supervision have been very important factors in the development of the Danish cattle industry, especially since 1902, when the laws relative to the promotion and breeding of domestic animals were revised, making provision for additional appropriations and support for the cattle breeders' associations. (See Appendix for details.)

The following is a statement of the government appropriation in 1906 for the promotion of breeding and keeping of domestic animals:

| | |
|---|---|
| Premiums at agricultural association shows | $29,480 |
| Premiums at the breeding association shows under common management | 5,360 |
| Premiums for government stallion shows | 20,100 |
| Premiums for government bull shows | 20,100 |
| Horse-breeding associations | 32,160 |
| Cattle breeders' associations | 37,520 |
| Swine breeders' associations | 1,072 |
| Sheep breeders' associations | 1,340 |
| Cow-test associations | 20,100 |
| Salaries to association experts | 8,040 |

| | |
|---|---|
| For competitive dairy test | $6,700 |
| Breeding centers for swine | 12,060 |
| Publishing herd books | 5,360 |
| Miscellaneous institutions for the improvement of domestic animals | 10,720 |
| Government show commissions | 10,318 |
| For the eradication of certain contagious diseases and to prevent the spread of tuberculosis | 53,600 |
| Total | 274,030 |

The total state appropriations for the promotion of agriculture amounted to $1,120,930. This is a very large sum of money when compared with the appropriations by our Federal and State governments for similar work. It should be considered also that Denmark is a very small country, only a little over one-fourth the size of the State of Iowa, although the population is slightly larger—about 2½ millions. Furthermore, much more can be accomplished for this sum of money in Denmark than can be accomplished for a similar amount in the United States. For instance, the average wages of 106 assistants in charge of the test association on the island of Funen in 1906 was about $120 per year. The state appropriation for a cow-test association is $67. Thus a little over one-half of the assistants' wages was paid by the State.

One striking feature of the state appropriations, which is also alluded to elsewhere, is that of giving in proportion to the interest shown in the enterprises undertaken by the various associations. The fact that the State distributes money in proportion to the amount the breeding associations or agricultural societies themselves can produce is an incentive for the associations to raise as much money as possible and helps greatly to keep up interest in the work.

It must not be understood, however, that the Government controls all the agricultural associations receiving government aid. Although there is a well-regulated supervision of government money expended, it is a supervision which is optional to the cattle owners. The farmers, in forming cooperative associations and accepting the government aid, voluntarily put themselves under its supervision. As has already been mentioned, there were in Denmark in 1906, besides 1,095 breeding associations receiving government aid, 30 cooperative breeding associations which did not receive government aid, and consequently were not subjected to government supervision. The Government does not try to force its supervision upon the cooperative societies, neither does it try to discourage or check individual enterprise. The great advancement in cooperation has come from the people themselves. They have felt the need and benefit of cooperation. Each community seems to have furnished its own leaders and organizers, of whom many have spent a great deal of their own time and money in fostering the spirit of cooperation and in getting the people to see that the welfare of a country or of a community is bound up in the success and welfare of all its individuals and not in the success of a few. The Government has in a wise manner encouraged cooperative enterprises and rendered them stable. It has guided, aided, and bound together the organizations which served the best interests of all, so that they have become powerful agencies in the developing of the agricultural resources of the country and in promoting the welfare of its inhabitants.

Besides the large amount of money set aside by the Government for premiums at fairs and shows, as well as other appropriations which indirectly benefit the cattle breeders' associations, the direct appropriation for these associations in 1906 was $42,880. As before intimated each eligible association receives an amount varying from $34.84 to $45.56 per bull yearly, according to a classification adopted by the common management in which the good qualities of the bull and the work of the association in general are considered. (For details see section 14 in the Appendix, p. 36.)

Additional aid to the extent of from $13.40 to $40.20 may be obtained by breeding associations for special work in developing good families. Furthermore, if the association employs an assistant to keep records of the yield of milk and butter fat and the food consumed by the individual cows in the herds, it can be recognized as a cow-test association and receive an additional aid of $67 a year.

The aid to the cattle breeders' associations is apportioned by the minister of agriculture. The individual association applies for government aid through its common-management association, which refers the application to a still higher common management, the latter representing also the cow-test associations and agricultural societies for the district. This body considers the application and recommends to the department of agriculture. Associations receiving government aid are at all times subject to government inspection.

### ELIGIBILITY FOR GOVERNMENT AID.

In order to be eligible for government aid the cattle breeders' associations must have their by-laws approved by the minister of agriculture. The by-laws must contain provisions to the effect that the cows of the members shall be selected under the proper supervision, that the bull shall be examined twice a year by a veterinarian, and that the herds shall be inspected on the farms at least once a year by the board of directors or a committee of its members. Before government aid will be granted for a specified bull he must have received a premium or "recognition money" at a government show or at a breeding-association show supported by the government.

In explanation of the phrase "recognition money," it should be stated that at these shows, in addition to the regular premiums distributed, a certain sum of money is distributed among the bulls which do not receive premiums, but which are considered worthy of recognition as good bulls. This is called "recognition money."

A bull to be eligible for government aid must, furthermore, win a premium every year at a breeding-association show until such time as his offspring receive premiums; or, after having reached the age of 3 years, he must at least be found worthy of a premium at a government show unless special conditions should make it impossible to put the animal on exhibition, in which case the fact must be certified to by the chairman of the district show. No aid shall be granted before the bull reaches the age of 1¾ years, and then only as long as he shall be in possession of his full breeding capacity.

In case a bull is sold, the government aid can be retained if the association, within two months after the sale, buys another bull meeting the above-named requirements.

The Government not only requires certain eligibility rules before granting aid, but after this is done it also requires a complete report from each association at the end of the year, giving detailed information concerning the bull, the cows, and their offspring, and the financial condition of the association. This supervision keeps the Government in touch with the results and progress of the work in all parts of the country. It gives an opportunity for comparison between individual associations, which often yields much valuable information in regard to the success of the work. Furthermore, the fact that a very detailed report is required once a year means that all records and books of the association are completed at that time, which helps to eliminate to some extent the not uncommon carelessness of secretaries and treasurers of local organizations where promptness is not compulsory.

The following blanks used for making application for government aid and for making yearly reports will illustrate the extent and details of the government supervision:

### APPLICATION BLANK FOR GOVERNMENT AID TO CATTLE-BREEDERS' ASSOCIATIONS.[a]

Name of breeding association: ———.
Name of common management association: ———.

---

[a] A copy of the laws of the association must accompany the application. If all associations under the same common management have uniform laws, one copy will suffice for all the associations.

To the Department of Agriculture:

The breeding association of ——— in ——— province hereby applies for government aid for the keeping of the association bulls, according to law relating to domestic animals of May 23, 1902.

The association was formed the ———, and has to-day —— members, with —— selected cows. The association has subordinated itself to the common management of the ———, the declaration of which will be found on the opposite page.

The bull belonging to the association is of the ——— breed, is named ———, was born in the month of ———, in the year ——, with ———, and was purchased at a price of ———, of which ——— was cash and ——— on time. Its pedigree will be found on the third page. It has been owned and utilized by the association since ———, and has received premiums at the following shows (name the circuit):

| Government shows. | Year. | Prize. | Breeding-association shows. | Year. | Prize. |
|---|---|---|---|---|---|
| | | | | | |

Certificate of the veterinarian relating to the health and breeding capacity of the bull will be found on next page.

Concerning the work of the association during the current fiscal year, the following information is rendered: [If the association has changed bull since the last 1st of April, it must be stated when and for what reason the former bull was sold.]

The breeding association of ———, the ———, 190—.

(Signature of president) ——— ———, *President.*

P. O. address ——— ———.

VETERINARIAN'S CERTIFICATE.

The undersigned has to-day examined the above-named cattle-breeders' association bull, named ———, and found it healthy, and particularly not suffering from any disease liable to be transmitted by service, and in possession of its breeding capacity.

———, the ———, 190—.

(Signed) ——— ———,
*Authorized veterinarian.*

Indorsement of the chairman of the common management:

This application is recommended.

———, the ———, 190—.

(Signature) ——— ———,
*Chairman of* ———.

REPORT TO BE SENT TO THE DEPARTMENT OF AGRICULTURE ON THE WORK OF CATTLE BREEDERS' ASSOCIATIONS RECEIVING GOVERNMENT AID.

To the DEPARTMENT OF AGRICULTURE.

## REPORT

for the year from April 1, 190—, to March 31, 190—, from ——— cattle breeders' association, subordinated to ——— common management.

| Questions. | Answers. |
|---|---|
| **I. THE ASSOCIATION.** | |
| 1. When was the association formed? | |
| 2. How many members had the asso-tion March 31, 190—? | |
| 3. How many members are also members of a cow-test association? | |
| **II. INFORMATION CONCERNING THE BULL OWNED BY THE ASSOCIATION MARCH 31, 190—, AT THE END OF THE FISCAL YEAR.** | |
| 1. Name of bull? | |
| 2. Breed of bull? | |
| 3. When born? | |
| 4. Where born? | |
| 5. Where reared? | |
| 6. When bought? | |
| 7. The price paid for the bull? (The amount on time stated separately.) | |
| 8. When and where did the bull last receive a premium, and what amount? | |

| Questions. | Answers. |
|---|---|
| III. OTHER INFORMATION CONCERNING THE BULL. | |
| 9. How many selected cows did the bull serve during last fiscal year? | |
| 10. How many calves were dropped last fiscal year by cows served by the bull? | |
| 11. How often, in the course of the year, has the bull been examined by a veterinarian, and at what times? | |
| 12. With whom is the bull stabled? (Name and post-office address.) | |
| IV. THE COWS. | |
| 1. How many selected cows did the association have March 31, 190—? | |
| 2. Who selected the cows? | |
| 3. Are the selected cows marked? | |
| 4. Are the selected cows divided into classes? How many in each? | |
| 5. Have the herds of the members been examined at their farms by direction of the management? Who made the examination? When was it made? | |
| 6. How many cows, all told, are owned by the members? | |
| 7. How many cases of abortion occurred with one or more of the members of the association? | |
| 8. Has a collective examination of the selected cows been made during the year? When and where? | |
| 9. What service fee has been charged? | |

| Questions. | Answers. |
|---|---|
| **V. THE OFFSPRING.** | |
| 1. Has the offspring of the selected cows been collectively examined by the management of the association? If so, when and where? | |
| 2. What is their opinion about the offspring on the whole? | |
| 3. Is the offspring marked according to a certain system? | |

### VI. OTHER REMARKS.

(If the association, in the course of the year, has changed bull, information concerning the time and reason should be given here.)

*Account for the year from April 1, 190—, to March 31, 190—.*

| EXPENSES. | | | REVENUE. | | |
|---|---|---|---|---|---|
| 1. Deficit from last year..... | | | 1. Cash from last year...... | | |
| 2. For feeding bull.......... | | | 2. Service fees............. | | |
| 3. Insurance of bull......... | | | 3. Prizes.................... | | |
| 4. Veterinarian............. | | | 4. Government aid for the year.................. | | |
| 5. Exhibition of bull...... | | | 5. Other revenue........... | | |
| 6. Interest.................. | | | | | |
| 7. Payments................. | | | | | |
| 8. Other expenses........... | | | | | |
| Cash at end of year...... | | | Deficit at end of year... | | |
| Total expenses....... | | | Total revenue....... | | |

| | |
|---|---|
| Debt of the association March 31, 190—............................... | |
| Property of the association March 31, 190— (value of bull not included). | |

———, breeding association ———, 190—.

(Signed) ——— ———, *President.*

———, *Residence.*

———, *P. O. address.*

## VALUE OF SHOWS AND FAIRS.

Although the value of shows and showing may be questioned by some, it is the opinion of the Danish experts and the majority of the farmers that cattle shows and fairs have been a very important factor in developing the cattle breeders' associations as well as the whole cattle industry. As early as 1810 premiums for bulls were distributed in a few sections, but not until after 1852 did the practice become general throughout the country. In 1852 the Government appropriated $4,073.60 for the yearly distribution of premiums for live stock at fairs and shows. That the Government has considered this money well expended is shown by the gradual increase in the amount appropriated for such purposes, until in 1906 it reached $85,358.

The shows have gradually increased in number as well as in exhibits and attendance. People have come to appreciate more and more the educational benefit of showing, and the efforts of the Government and the management of the shows are directed toward making them as educational and of as much practical value to the people as possible.

The shows may be classified as follows:

1. Agricultural-association shows.
2. Shows of breeding associations under common managements.
3. Government bull shows.
4. Shows for young stock.
5. Agricultural conventions.

The agricultural-association shows get an annual subsidy from the Government equal to the amount the associations themselves appropriate for premiums for breeding animals. The shows of breeding associations under common management get twice the amount they themselves contribute for prizes. The government bull shows, which are more fully described in the succeeding chapter, get an annual appropriation, varying according to the recommendation of the bull-show commission.[a]

The first show for young stock was held in 1892. The aim of this show was to get together the best of all the young stock of all breeds from the whole country. In the development of the breeds the aim had been the fixing of certain characteristics. The bringing together of the young stock would afford an opportunity to study uniformity of development, as well as giving the best animals from the different show circuits an opportunity to compete against each other. These shows have now become annual affairs and are held in different locations each year, so as to make them as educative as possible. The number of entries and visitors has increased from year to year, for besides the educational value the shows have also come to be of considerable importance as a place to sell and buy breeding stock.

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[a] For details in regard to distribution of premiums see sections 1, 2, 4, p. 33, in Appendix.

Agricultural conventions are held from time to time. The principal object, as far as the cattle industry is concerned, is the same as for the yearly shows of young stock, except that animals of all ages are shown.

## GOVERNMENT SHOW COMMISSIONS AND BULL SHOWS.

The government show commission is a body of men appointed by the minister of agriculture, who supervises all the fairs and shows receiving state aid for premiums. The country is divided into thirteen districts, or circuits, in each of which is a bull commission. The chairman of this commission is appointed by the minister of agriculture and is a member of the government show commission, the rest of the members of the commission being appointed upon the recommendation of the agricultural societies in the district.

In 1906, $20,100 was appropriated for premiums at government bull shows, for bulls over 3 years old and in possession of full breeding power. In each of the thirteen show districts is held one or more annual bull shows, which, as a rule, are held in connection with other agricultural association shows. The amount of money appropriated by the government for premiums is distributed by the minister of agriculture among the show districts according to the recommendation of the chairman of the government show commission, who in advance has secured reports and recommendations from the chairman of the bull-show commissions. In the distribution are considered the number of animals which have been exhibited and have received premiums during the last year within the district, and the number of animals present at the last government show.

The government show commission prepares the necessary rules to guide the judges, thus assuring a uniform system of judging throughout the country.

The bull-show commission. however, decides upon the number and amount of premiums, the rules for distributing the same, and the place where the show is to be held. Furthermore, the commission judges the animals and distributes the premiums.

In awarding premiums the offspring of the competing animals are particularly considered, so that the principal part of the money expended is on account of the power of the bull to produce good offspring rather than for his individuality.

If a bull receives a premium the owner is under obligation to let the animal remain in the country for breeding purposes until the 1st of May the following year, which practically means for a year after the premium has been awarded, as all the shows are held during the summer months. In case the receiver of a premium decides to forego this obligation, the premium is to be returned to the government treasury.

It is also the duty of the chairman of the bull-show commission to see that records are kept containing accurate descriptions as well as information in regard to the pedigree and offspring of the bulls receiving premiums. A report on these topics and a statement of the amount distributed in premiums and otherwise expended for the holding of the bull show in each district is sent to the minister of agriculture each year before the end of October.

The importance of the bull shows in developing the cattle breeders' associations and in improving the cattle of the country can not be overestimated. As previously stated, in the distribution of the prizes by far the most importance is placed on the offspring. It is not uncommon for a bull or a stallion which has been unable to take premiums as an individual to receive high awards when shown with offspring. These shows therefore give to bulls which may be lacking somewhat in form and general appearance, but which have the power to produce good offspring, a chance to be recognized and valued as they deserve. On the other hand, bulls which have ranked high before the age of 3 years may be entirely out of the show ring later if they can not produce good offspring. As the real value of a bull depends upon the quality of his offspring more than on his appearance, these shows have had a marked influence upon the rapid improvement of the cattle.

## METHOD OF JUDGING AT SHOWS.

Many changes mark the development of the judging of cattle at shows. The scale of points on one of the first score cards in use was 24, giving 16 points for the escutcheon and 8 points for build and general appearance. This seemingly undue importance laid on the escutcheon was principally due to the Frenchman, Guenon, who at that time called special attention to the escutcheon as an indication of good milking capacity. The score card was gradually changed and broadened. More divisions in the scale of points were made as the importance of the different features which constituted a good dairy animal became clearer.

In 1887 the ancestors of the animals were for the first time considered in the judging, by giving 8 points in a scale of 72 for pedigree. In 1903 the government show commission revised the score card for dairy cattle as follows:

| | Points. |
|---|---|
| Form and size | 15 |
| Quality and dairy temperament | 12 |
| Milking qualities | 12 |
| Pedigree | 12 |
| Total | 51 |

The points given for pedigree were to be considered under the following heads:

| | Points. |
|---|---|
| *a.* Detailed information in regard to ancestors | 2 |
| *b.* Premiums awarded to the animals mentioned in pedigree | 3 |
| *c.* The importance of the family in the development of the breed | 3 |
| *d.* Detailed information in regard to amount of milk and per cent of fat in milk | 4 |
| Total | 12 |

In the judging of animals at fairs and shows it has become the aim more and more to place the animal according to its breeding value as shown by its offspring and by performance. Although the methods employed with this in view differ in various parts of the country, all are working toward this end. At a show held in Copenhagen in 1905 there was a class for herds of cows with authenticated records. In order to be eligible to this class heifers after the first calf had to show a record of at least 5,500 pounds of milk, with an average of 3.2 per cent fat. From heifers after second calf an average was required of at least 6,050 pounds for the two years, with 3.2 per cent fat, and for aged cows an average of 6,600 pounds of milk a year, with 3.2 per cent fat. In the herd contest the average per cent of fat in each herd exhibited was required to be at least 3.4 per cent. For every additional one-tenth of 1 per cent 1 point, not to exceed 9 points in all, was added to the total score.

The herd premiums were awarded first according to the appearance of the cows; then an additional premium was given for production. In the classification according to production, 330 pounds of butter was given 1 point, and an additional half point was given for each 11 pounds of butter over 330 pounds. Half a point was given for a fat content of 3.5 per cent, and for every additional one-tenth of 1 per cent half a point was added.[a]

Upon this scale the herds were recognized in the following classes:

| | |
|---|---|
| Class I A | 7 points or more. |
| Class I B | 5 to 7 points. |
| Class II A | 3 to 5 points. |
| Class II B | 1 to 3 points. |

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[a] The customary method of calculating butter is as follows: The loss of fat in skim milk and buttermilk is estimated at 0.15 pound of fat in every 100 pounds of milk; and the butter is considered to contain 86 per cent butter fat. This gives the formula:

$$[(\text{Pounds of milk} \times \text{percentage of butter fat}) - (\text{pounds of milk} \times 0.0015)] \times \frac{100}{86} = \text{pounds of butter.}$$

By this method of judging both the quantity and the quality of the milk was taken into consideration as well as the individuality of the animals.

At an agricultural convention in the island of Funen in 1906, in order for a bull to compete for prizes it was required to present authenticated records of his dam for at least two years. Furthermore, her production had to be at least 198 pounds[a] of butter a year for her first and second years, and 275 pounds for the following years. After complying with these requirements the bulls could be entered in two classes, to be judged either for their individuality or for their offspring.

Not only in Denmark, but also in other European countries, much stress is laid upon pedigree and yield in the judging of dairy animals. In Sweden the following score card has been successfully used in the judging of young bulls:

| | Points. |
|---|---|
| Pedigree | 3 |
| Yield of ancestors | 3 |
| Form, general appearance, and strength | 3 |
| Total | 9 |

Under pedigree are especially considered the male ancestors and their power to transmit their characteristics, and under the yield of ancestors is considered the amount produced of both milk and butter.

That the above methods of judging can be carried out successfully is principally due to the cow-test associations, the records of which are taken as authenticated for this work. It has been a point for much discussion as to how much importance should be placed upon pedigree and how much upon records in the judging of an animal. To go from a system of judging on individuality alone to a system of judging almost entirely on the records would be going from one extreme to another. The fact that form is the result of function does not make the judging on individuality without foundation. However, by also placing due importance on the ancestors and their production, stress is laid upon those points that specially determine the value of the animal for both breeding and economic purposes.

## MARKET PRICES OF BULLS AND CONDITIONS OF TRANSFER.

In 1906 the average price for bulls of the Jutland breed was $406.27, $152.76 of this being cash and $253.51 "on condition." The average for the Red Danish breed was $480.79, of which $192.69

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[a] One Danish pound equals 1.102368 English pounds. The weights mentioned in this bulletin are all given in English pounds, taking 1.1 English as equal to 1 Danish.

was cash and $288.10 "on condition." The conditional part of the sale is explained as follows:

Since, in order to obtain government aid, bulls must be recognized at the shows receiving government support, it is common to buy bulls for a certain sum of money payable on delivery and an additional sum according to the recognition the bull receives in the show ring. A further sum may also be paid if the bull gets over a certain per cent of the cows he serves with calf or, in case he is shown the first time with offspring, if he receives a premium of not less than a certain rank. As it may take two years before some of the terms can be decided upon, the buyer is, of course, responsible and liable to the seller for the treatment the animal receives up to that time. The seller must furnish a guaranteed pedigree as well as health certificate, including test for tuberculosis, and also guarantee that the bull is in possession of his breeding power. The fact that the greater part of the purchase price of the animals depends upon conditions, as stated above, shows how the people value and are willing to pay for those qualities in the bull which can not be judged from his outward appearance, but which largely determine his value for improving the herd. (See Appendix, p. 38, for complete form of contract commonly used in sale of bulls.)

## DIFFICULTIES ENCOUNTERED IN THE WORK OF THE ASSOCIATIONS.

Some of the difficulties the associations have had to meet and which in many cases hinder the good results to be expected from this work are:

1. The associations do not as a rule keep their bulls long enough.

Many of the associations keep their bulls only one, two, or at the most three years. This time is altogether too short to ascertain the real breeding value of the bull as shown by the offspring. The principal reasons for this frequent change of bulls are that many farmers fear evil effects from inbreeding, and that the bulls become either vicious or nonbreeders. That they become vicious is often attributed to the custom of changing the boarding place of the bull from year to year in order, perhaps, to save a few dollars on his keep. Often the bulls become nonbreeders due to overfattening, lack of exercise, or too heavy service when young.

The result of this frequent change of bulls, even of the same breed, is in many cases a hindrance to the development of the cattle industry in the community, since the offspring from year to year are lacking in uniformity.

2. Some associations have too large a membership.

It can readily be understood that if an association is too large in membership and in number of cows the benefit to the individual member becomes smaller. Associations having a membership of from 40 to 60, with from 300 to 400 cows and only 1 bull, will not be nearly so important as will the smaller associations. It is considered that a full-grown bull can be used on 125 to 150 cows a year if the time of calving is scattered throughout the year; but as a rule the cows are bred during a few months, and in such cases the ratio of cows to bulls should not be more than 50 to 1, especially if the association is aiming to keep the bull for several years.

3. Frequency of abortions.

Although all cattle breeders' associations have rules prohibiting cows that have aborted from being bred to association bulls, yet in many cases abortions have been spread by the bull from herd to herd. Abortion in a herd not only causes an immediate loss due to a lower production, but may check improvement in the herd for several years. To prevent the spread of the disease, not only is great care taken in disinfecting the bull after each service, but in some associations there is carried out a frequent systematic veterinary inspection and examination of all cows in the association.

4. Members do not always use the association bull.

In some communities the members may have to lead their cows a considerable distance to reach the association bull. This, as also the higher service fee, often causes members who are not fully alive to the importance of a well-bred bull in improving the herd to neglect to bring their cows to the association bull.

## INFLUENCE OF CATTLE BREEDERS' ASSOCIATIONS UPON THE DAIRY INDUSTRY.

The influence of the cattle breeders' associations is especially marked along the following lines:

1. By organization and cooperation it became possible for the smaller farmers to obtain a rapid improvement in their herds, which otherwise would practically have been impossible.
2. They have constantly and forcibly demonstrated to the farmer the value of a purebred bull of recognized family in the improvement of the herd.
3. The herd books and records kept by the associations have taught the farmer to appreciate the value of a pedigree in the selection of breeding animals.
4. By cooperating with the cow-test associations and agricultural societies it has become possible to employ many cattle experts, who not only have acted as educators and advisers but to whom is due the credit for the uniform and systematic way in which this work is carried on throughout the country.

The important part played by the breeders' associations in the improvement of the cattle is quite noticeable at the fairs and shows. A few years ago the greater portion of the animals exhibited, especially bulls, belonged to individual farmers owning large herds. To-day not only do more bulls in the show rings belong to the breeders' associations, but these most frequently carry off the highest honors. By means of these associations a large number of the smaller farmers who could not afford to keep or buy a high-priced bull for a few cows have had an equal opportunity for improving their herds, as well as equal chances at the shows, with the farmers who own the large herds. Furthermore, they have added greatly to the interest taken in the shows and fairs, as each member of an association takes a personal interest and pride in having his association bull successfully meet the often very keen competition.

## GROWTH OF THE INDUSTRY.

The number of cows in Denmark in 1866 was 812,000, with an average annual production of about 2,200 pounds of milk per cow. The number of cows in 1903 was 1,089,073, with an average production of 5,720 pounds. The average annual production at the present time is estimated to be about 6,600 pounds of milk per cow.

The increase in the production has been specially noticeable as the cooperative movement has taken hold of branch after branch of the cattle industry as well as other phases of agricultural work which indirectly would influence its development. The period from 1880 to 1883 will always be memorable in the history of Danish agriculture, because it marks the organization of the first cooperative creamery, the first permanent cattle breeders' association, the publishing of the first public herd book, and the appointment of the committee for the preservation and improvement of the Jutland breed. It also marks the period at which Denmark ceased to export grain, due to the fact that it proved more economical to feed it to the cattle. Since then not only has the grain raised in the country been fed to the live stock, but the importation of grain and concentrated feedstuffs has increased from year to year. In 1907 the imports amounted to 1,608 million pounds of grain, 987 million pounds of oil meal and oil cake, and 131 million pounds of bran and gluten, a total of 2,726 million pounds. The larger portion of this large total of feedstuffs has been used in the production of butter, of which, in 1907, 200,069,200 pounds were exported to England. But in addition it has added thousands of dollars worth of plant food to the soil. The fertility once lost through the marketing of the grain from the farms has not only been replaced, but in many sections the soil is richer, and is at present producing larger crops than ever in the past.

It is well to remember that the great improvement effected in Danish cattle has not been brought about by importation of high-priced animals from other countries, but is simply due to organization and cooperation, careful selection, systematic application of the principles of breeding, and good care and liberal feeding of the cattle. It is the result of having a definite purpose in view which is never lost sight of. The Jutland cow, once primarily kept for the production of beef, has been changed into a profitable dairy cow. The average annual production of the Red Danish cows, according to the creamery statistics for the island of Funen in 1907, was 6,930 pounds per cow, an amount that will compare favorably with any dairy breed.

## ACKNOWLEDGMENTS.

The author desires to acknowledge the great courtesy received in Denmark, not only from the officials and experts connected with the agricultural department and the agricultural societies, but on every hand where information was sought. He is especially indebted to Lars Frederiksen, one of the cattle experts employed by the Jutland Agricultural Society, for the valuable references given to agricultural reports and to other agricultural literature.

The following literature has been made use of in preparing this bulletin:

Konsulentberetning of Jydske Landboforeninger, 1905. S. P. Petersen.
Husdyrbrug of 1906. Axel Appel.
Kvaegavl og Kvaegopdraet. A. Svendsen.
Landokonomisk Aarbog, 1907. H. C. Larsen.
Kvaegbrugets Udvikling i Danmark, A. Appel og P. A. Morkeberg.

# APPENDIX.

## BY-LAWS FOR CATTLE BREEDERS' ASSOCIATIONS UNDER COMMON MANAGEMENT ON THE ISLAND OF FUNEN.

SECTION 1. The aim of the cattle breeders' association is to produce the sure and rapid development of a sound, well-built, productive, Red Danish breed of milch cows. The aim shall be reached principally by the purchase of meritorious herd bulls, by selecting the best dams (the selection being, as much as possible, based on information about yielding capacity and pedigree), by a rational treatment of the offspring, and by the holding of local shows according to rules stated below.

SEC. 2. (*a*) Every cattle breeder within the district is eligible to membership who subscribes to these by-laws and has in his herd at least one cow which is considered by the management of the association to be worthy of joining the ranks of the breeding animals.

(*b*) Members who join later enter with rights and obligations in proportion to and in accordance with the state of affairs approved by the last general meeting.

SEC. 3. Members may be accepted at any time on application to the chairman or a member of the board of directors.

SEC. 4. Withdrawals from the association can take place only on the 1st of April of each year, and notification in writing must be sent to the chairman not less than one year in advance and be receipted for. From the day of receipt of the notification the member shall have no vote.

SEC. 5. The management of the association shall be vested in a board of directors of ——— members, elected for four years by the general meeting. From the board of directors, which elects its own chairman, ——— members shall retire, alternately, every other year; the first time the retirement shall be by lot, later according to turn. Reelection is permitted.

The district of the association shall be divided into circuits, with a member of the board as manager of each circuit.

SEC. 6. The members of the board of directors shall see to the enforcement of the laws and take care of the affairs of the association. When the chairman or three of the members desire, meetings of the board shall be held. Both at these and at the general meetings records shall be kept.

The board shall select, purchase, offer for service, exclude, and sell the herd bulls of the association, select the cows of the members, act as judges at the local shows, and give the members advice regarding their bookkeeping.

The chairman shall call the meetings of the board of directors, decide when and where they shall be held, preside at the same, and keep the minutes. He shall represent the association, keep its correspondence and accounts, and act as its treasurer. He shall be responsible for the funds of the association intrusted to him and endeavor to make them profitable.

The circuit managers shall work for the benefit of the association in their respective districts and pay strict attention to the work there. The board of directors or a committee of the members shall, once a year, inspect the herds of the members on their farms.

SEC. 7. The herd bull must be sound and well built, of Red Danish milking breed, and recognized good pedigree. He shall be insured, and twice a year shall be examined by a veterinary surgeon. He should not be utilized for breeding purposes until he reaches the age of 1¾ years. When purchasing bulls, the association should secure guarantee of breeding capacity. The bull shall be exhibited every year until he shall have received premiums on account of his offspring. Until the age of 3 years he shall be exhibited at a breeding association show subsidized by the Government; and after the age of 3 years at the government show. He shall also be exhibited at the local shows.

SEC. 8. The members are entitled to have their cows served by the association bull, provided that the cows are not subject to abortion, are otherwise healthy, and are approved by the board of directors.

SEC. 9. The fee for service shall be determined every year by the board of directors, and shall be paid by the members in proportion to the number of their eligible cows.

SEC. 10. Every member must keep the records directed by the board of directors and is bound to exhibit, at the local shows arranged by the board of directors, all selected cows and their offspring by the association bull until the heifers become pregnant for the first time and the bulls reach the age of 2 years. Calves less than 3 months old need not be exhibited. Each calf shall be earmarked with the number of its dam, according to a method adopted by the management.

The members shall be bound on the demand of the board of directors to exhibit the offspring of the association bull, if such are in existence, at the annual offspring shows preceding the government shows.

SEC. 11. The cows shall be selected and a record kept in the selection book. The selection shall be conducted under proper supervision,[a] but may take place at any time of the year, and either at the farms or at the local shows.

Only healthy animals shall be admitted. According to their characteristics they shall be divided into two classes, A and B, the former of which includes animals *especially* suited for breeding and the latter comprises animals which *may* be utilized for breeding purposes. Every animal shall have its number branded on the back of the right horn. Cows of class A also have an A branded on the back of the left horn. Branding may be dispensed with when the cows are otherwise marked in a safe manner.

SEC. 12. The board of directors fixes the time and place of the local shows, and notifies the members eight days in advance. Any cows excluded by the circuit manager, with the acquiescence of the owner, need not be exhibited, as they are considered stricken out.

SEC. 13. The fiscal year of the association shall run from the 1st of April to the 31st of March. The chairman shall deliver his accounts, and they shall be returned to him in the course of eight days.

For accounts relating to the individual cows and the association bulls the adopted forms are used. When the selected cows have been accepted by a cow-test association, the forms of the latter are used.

SEC. 14. A regular general meeting shall be held once a year after eight days previous notification. At the annual meeting the audited accounts shall be produced, and the chairman shall give a short report of the work of the association during the past year. Furthermore, new members of the board of directors shall be elected to succeed the retiring members and also two auditors.

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[a] See law on domestic animals, in Appendix, paragraph 14.

All questions except those mentioned in section 16 are decided upon by a majority vote. The votes must be delivered in person. At the general meeting all matters or questions communicated to the chairman in writing at least four days prior to the meeting, or proposed by the board of directors, are discussed and acted upon.

Extra general meetings may be called by the board of directors, and must be called when one-third of the members so desire. The call shall be issued as aforesaid.

SEC. 15. The members are jointly responsible for all debts contracted in accordance with the action of the general meeting and for deficits in the annual accounts or in the settlement of the financial affairs of the association when such settlement has to be made on account of the death or sale of bulls or for any other reason; each individual's liability being in proportion to the greatest number of cows registered as belonging to him at any time during the fiscal year, regardless of whether some of them were sold, killed, or stricken out. At withdrawals the withdrawing member, in order to be relieved of his liability, must pay the proportionate portion of the debt of the association, according to a statement rendered by the board and approved by the general meeting. He shall not be entitled to any portion of a possible surplus.

SEC. 16. The dissolution of the association can only be agreed upon by a general meeting where three fourth of the members are present and when three-fourths of those present vote in favor thereof. If no quorum should be obtained by the first call, a new general meeting shall decide by a majority vote, regardless of the number of members present.

## LAW RELATING TO INSTITUTIONS FOR THE PROMOTION OF THE BREEDING AND KEEPING OF DOMESTIC ANIMALS.[a]

The institutions named below, for the promotion of the breeding and keeping of domestic animals, shall be aided by government subsidies as follows:

### DISTRIBUTION OF PREMIUMS AT SHOWS.

1. The provincial agricultural association fairs or shows may receive a subsidy which, with the restriction named in section 3, shall be equal to the amount the associations themselves appropriate for premiums for breeding animals. Agricultural associations holding their annual shows in common may receive, subject to the discretion of the minister of agriculture, a further aid of 10 per cent of the amount named. (See secs. 2 and 3.)

2. Shows in common. (See secs. 2 and 4 to 6.)

(*a*) The shows conducted by associations under common management may be aided to the amount of twice as much as the interested associations themselves contribute for prizes at these shows.

4. Government shows for bulls may receive the amount of 75,000 kroner ($20,100). (See secs. 2 and 7 to 11.)

### BREEDING ASSOCIATIONS.

6. Cattle breeding associations may receive 150 kroner ($40.20) for each bull belonging to the association. (See secs. 12 and 14.)

7. Breeding associations specially apt to develop good strains may receive sums up to 20,000 kroner ($5,360). (See sec. 15.)

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[a] Only those clauses which influence the cattle industry are here quoted.

### OTHER INSTITUTIONS RELATING TO THE BREEDING AND KEEPING OF DOMESTIC ANIMALS.

9. Test associations may receive up to 250 kroner ($67) each; not, however, to exceed a total amount of 120,000 kroner ($32,160). (See sec. 17.)

10. For competitions between entire herds there may be appropriated an amount of not more than 25,000 kroner ($6,700). (See sec. 18.)

13. For the publication of herd books, an amount of not more than 20,000 kroner ($5,360). (See sec. 21.)

14. For experts in breeding, a subsidy of sums up to three-fifths of their annual salaries; not, however, to exceed 30,000 kroner ($8,040). (See sec. 22.)

15. Institutions not included in those above named, but aiming at the promotion of the breeding and keeping of domestic animals, and in the judgment of the minister of agriculture deserving support, shall receive an amount not to exceed 40,000 kroner ($10,720).

Furthermore, the Government shall defray the per diem and transportation expenses of the chairmen of the bull and stallion show commissions, of the judges at the government shows, and of the supervisors of the shows of the breeding associations, and the expenses connected with the publication of the reports of the government show commissions.

### AID FOR PREMIUMS AT SHOWS.[a]

SEC. 2. In awarding premiums according to this law, everything else being equal, the first animals to be considered shall be such as have prominent marks of their breed, have reliable and instructive pedigree records, and belong to good, and as far as possible, pure breeds and families.

It shall also be looked after that animals having received premiums at one show shall not receive such at another show in the same year; the cooperative shows mentioned in section 1, paragraph 2, and shows at agricultural conventions, however, excepted.

SEC. 3. The government aid mentioned in section 1, paragraph 1, shall, in the proportion there stated, be distributed by the minister of agriculture among the agricultural associations working for the promotion of the breeding and keeping of domestic animals; provided, however, that no association which has not been in existence for one year, and has not at least 150 contributing members, with annual contributions aggregating at least 300 kroner ($80.40), shall receive government aid (provided, however, that the minister of agriculture, when special geographical conditions make it desirable, may ignore this rule); and further provided, that the number of kroner in the subsidy shall not be more than four times the number of contributing members in the association.

The amounts appropriated may be used for premiums and recognition money[b] for:

Bulls between 1 and 3 years old.

Cows and heifers; provided that individual cows or heifers shall not receive prizes when belonging to herds of more than six milk cows.

Herds of at least three members, the female animals of which must have been born in the ownership of the exhibitor, or else reared by him, and in the latter case must have been bought by him before they were 3 months old; and family groups of cattle.

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[a] Section 1 is a summary of the provisions stated in more detail in section 2 and following sections.

[b] The term "recognition money" is explained on p. 16.

Bulls under 2 years of age and mares under 4 years can be awarded recognition money only.

The amount by which the subsidy may be increased for associations which, instead of holding their shows separately, hold a yearly show in common,[a] may by the minister of agriculture be allowed to be used for either premiums or expenses.

The award of premiums, both at the shows of single associations and at shows held under common management, shall be made by a judging committee chosen by the association. Associations which desire to be considered in the allotment of subsidies from the government treasury must, before the end of March, make application therefor to the minister of agriculture, the application to be accompanied by information as to whether they fulfill the conditions required for the granting of subsidies, and as to the size of the fund which the associations themselves have decided to distribute during that year in premiums.

The time for holding shows is to be determined by the associations holding same, after consultation with the government show commissioner for the district in which each association is located. (See Sec. 11.)

Premiums may be awarded only to such animals as are pledged to be kept in the country for breeding purposes for at least one year after the payment of the premium. If any such animal is sold abroad before the expiration of one year the premium shall be refunded.

In other details the rules for distribution of premiums shall be made by the associations themselves. At every distribution a record must be kept in which all animals that are awarded premiums shall be noted, with a short description of their breeding and characteristics, on forms approved by the minister of agriculture. An extract from this record shall be sent each October to the minister of Agriculture, who thereafter will demand the return of such subsidies as any association may not have used or which are distributed or kept contrary to the foregoing regulations.

Sec. 4. The aid mentioned in section 1, paragraph 2a, shall be distributed, in the proportion there stated, by the minister of agriculture, as premiums at the shows held by associations under common management, which, besides the kinds of animals mentioned in section 3, may comprise other gatherings of horses and cattle and, with a regular intermission of three years, older stallions and bulls.

Sec. 7. The amount of 75,000 kroner ($20,100) mentioned in section 1, paragraph 4, shall be used for premiums for bulls, only bulls more than 3 years old and still strong and in possession of full breeding capacity being eligible.

In every show district shall be held an annual stallion show; while the bull-show commissions in one or more connected show districts, when conditions make it desirable, shall hold annual shows for smaller districts, the number of which must not exceed the number of counties (Amtsraadskredse) in said show district or districts, and the boundaries of which, as much as possible, shall coincide with those of the counties, provided that considerations as to the kind of herds or geographical conditions do not necessitate other boundaries. The division into districts must be approved by the minister of agriculture, and can not be changed without his consent, after a new general election of bull-show commissioners. Changes in the district divisions necessitated by the appearance of contagious diseases may be made by the minister of agriculture.

The amount appropriated by the Government for premiums for stallions and bulls shall be distributed by the minister of agriculture among the show districts, according to recommendation from the chairman of the government bull-show commission, who shall secure reports and recommendations in advance from the chairmen of the stallion[a] and bull show commissions, which reports and recommendations shall be forwarded to the minister of agriculture at the same time as the recommendation of the chairman.

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[a] As provided in section 1, paragraphs 1 and 2*a*.

In the distribution shall be considered the number of animals that have been exhibited and have received premiums during the preceding year and the statistical information gained by the last enumeration of cattle at the last government shows, which information shall be forwarded by the chairman of the government show commission to the chairmen of the stallion and bull show commissions, who at the same time shall be requested to report.

SEC. 8. The government shows shall be managed by stallion and bull commissions, respectively, the chairmen of which shall be appointed by the minister of agriculture, and the other members of which shall be elected for a term of three years by the county boards from among the men proposed by the agricultural associations indicated below.

To the bull commissions two members and two alternates shall be elected by the county boards in the show districts. In case of a tie vote the election shall be decided by lot. Three months prior to the election the county chairman shall request each agricultural association in the district which has 150 members, in the previous year has appropriated at least 300 kroner ($80.40) of its own means for premiums, and holds annual shows, to propose in writing a number of members and alternates equal to the number to be elected by the county board, and from among that number the members shall be chosen. If there should be only one agricultural association in the county, the latter shall propose twice as many members and alternates as the county board shall elect. Each and every stallion and bull show commission shall from among its members elect a secretary, who shall act until the following year's stallion or bull show shall have been held.

SEC. 9. The stallion and bull show commissions shall decide upon the number and amount of premiums, the rules for distributing the same, the place where the show shall be held, and the expenses necessary.

These decisions, as well as the changes in and amendments to the same, adopted by the commission shall be published by the commission.

The government show commission shall prepare the necessary rules to guide the judges.

The commissioners shall act as judges at the horse and bull shows, respectively, and shall distribute the premiums.

In awarding premiums the offspring of the competing animals shall be particularly considered, so that the principal part of the amount shall be expended for premiums for good offspring.

Bulls that have received premiums may be branded with the mark of the commission, but only when the owner so desires.

Whoever receives a premium thereby assumes the obligation to let the animal, having been considered worthy of it, remain in the country for breeding purposes, if it is a bull, until the 1st of May of the following year.

Should the receivers of premiums neglect to fulfill this obligation, the premiums shall be returned to the treasury, unless the minister of agriculture shall admit that special reasons for such neglects have been proved. Amounts of premiums to be returned according to this regulation may be collected by legal proceedings.

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[a] Stallion show commissions and bull show commissions are independent commissions having separate funds for distribution. Sums of money quoted are used for promoting cattle industry only.

SEC. 10. The chairmen of the stallion and bull show commissions shall determine the time for holding stallion and bull shows. They shall preside at the meetings of the commissions and, with the assistance of the secretaries, keep records which, among other things, shall contain accurate descriptions of the stallions and bulls that have received premiums, and information regarding their pedigree and offspring. The chairmen shall receive the amounts appropriated for premiums by the Government and distribute the same. They also, before the end of October of each year, shall send to the minister of agriculture a complete report of the results of the shows, accompanied by a transcript of the records and a statement setting forth the amount distributed as premiums and expended for the holding of stallion and bull shows, etc.

The secretaries of the commissions, who on the whole shall take care of the preliminary preparation of the shows, shall advertise for not less than two weeks prior to the holding of the show, in the most widely circulated newspapers in the district, the place, the time, and the amount of premiums.

SEC. 11. The chairmen of the stallion and bull show commissions, in connection with the government expert in breeding of domestic animals, under the presidency of a man appointed by the minister of agriculture, shall form a government show commission, through which the supervision provided for in section 3 in the present law shall be conducted in such a way that the full commission shall divide the associations among its members, and one of the commission chairmen shall be present at each association show, with the right to take part in the deliberations and votes of the judging committee.

The government show commission shall hold a regular annual meeting, at which questions of importance for the work of the commission shall be brought up and discussed, and issue an annual report.

### AID TO BREEDING ASSOCIATIONS.

SEC. 12. The aid to breeding associations discussed below shall be distributed by the minister of agriculture and only be given to associations, the aims of which are recognized as good and useful and which are recommended by the common management associations of the province. Applications for aid shall be sent through the latter.

The breeding associations are, as far as the application of the government aid is concerned, subjected to the supervision of the minister of agriculture.

Should an association dissolve during the fiscal year for which government aid has been received, the minister of agriculture shall be entitled to claim the reimbursement of the amount or a proportionate part of the same; for this reimbursement the members of the board of directors are jointly (one for all and all for one) responsible.

SEC. 14. The cattle breeders' associations referred to in section 1, paragraph 6, in order to be eligible for government aid, must have their by-laws approved by the minister of agriculture. The by-laws must contain provisions to the effect that the cows of the members shall be selected under proper supervision, that the bull shall be examined twice a year by a veterinarian, and that the herds shall be inspected at their homes at least once a year by the board of directors or a committee of its members. The government aid shall be granted for a specified bull that must have received a premium or recognition money[a] at a government show or at a breeding association show supported by the Government. Besides, the bull, until he shall have received offspring premium, must receive every year a premium at a breeding association show or, after having reached the age of 3 years, must at least be considered worthy of a premium at a government show, unless special conditions should make this impossible, in which latter case the fact must be certified to by the chairman of the district show. No aid shall be granted before the bull reaches the age of 1¾ years; and only as long as the bull owned by the association shall be in possession of his full breeding capacity.

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[a] See p. 16.

The annual amount, counting from the day the bull was received by the association, shall be 150 kroner ($40.20) for each bull; provided, however, that in proportion to the number of bulls the amount intended for breeding associations under a common provincial management shall be distributed in amounts ranging from 130 kroner ($34.84) to 170 kroner ($45.56), according to a classification adopted by the common management at which the good qualities of the bull as well as the work of the association in general shall be considered.

If the bull should be sold, the government aid shall be kept without discount, provided, that the association, within two months after the sale, shall purchase another bull meeting the requirements named above.

SEC. 15. The amount of aid mentioned in section 1, paragraph 7, may be utilized by the minister of agriculture for the further encouragement of breeding associations which, by the exhibition of excellent young animals, prove themselves to possess special adaptation for the development of valuable strains of cattle.

The passing of judgment on the young animals shall occur at the offspring shows conducted by the bull-show commissions, and with the commissioners as judges.

The aid, granted in amounts ranging from 50 kroner ($13.40) to 150 kroner ($40.20), shall be distributed according to the recommendation of the interested common-management associations.

In case the associations here mentioned have assistants to keep herd books and accounts of the yield and feeding of the individual cows, they may, in accordance with section 17, be granted additional aid as cow-test associations.

### AID TO OTHER INSTITUTIONS CONCERNED IN THE BREEDING AND KEEPING OF DOMESTIC ANIMALS.

SEC. 17. The aid mentioned in section 1, paragraph 9, shall be distributed by the minister of agriculture, in the proportion there indicated, to cow-testing associations which have as their aim to instruct cattle owners, increase the profits of cattle breeding, and promote the development of cattle breeds whose milk will yield an increased amount of butter; such efforts being made on the basis of investigations into the feeding, milk yield, and fat content of milk of individual cows.

Such associations must have at least 8 members and 200 cows; but the minister of agriculture may dispense with the requirement of such a number of members or cows, either in consideration of the scattered population of the locality and special local conditions, or because the association in question has taken up the work of testing and other branches of the trade, closely connected with the principal aims, or, finally, when breeding associations of the kind mentioned in section 15 are concerned.

Associations having a sufficient number of members and cows to form more than one association, and employing more than one assistant, may, at the discretion of the minister of agriculture, receive aid as more than one association.

Cattle breeders' associations or mergers of such, with cows to the number of 150, which have taken up the testing and examination of the yield and feeding of the cows, may secure aid as cow-testing associations.

The by-laws of the associations must be approved by the minister of agriculture, to whom applications for aid should be sent, accompanied by a declaration from the common-management association of the province.

SEC. 18. The aid mentioned in section 1, paragraph 10, may be used by the minister of agriculture for holding competitions between entire herds.

The passing of judgment shall be based on a two years' competition conducted by the common-management association of the district.

In passing judgment, besides the appearance and yielding capacity, the ability of the individuals to transfer the characteristics and good qualities of the breed to the offspring should be considered.

Judgment shall be passed by committees, each consisting of three members, one of whom shall be appointed by the minister of agriculture and the other two by the breeding association which conducts the competition.

The results of the competition shall be published.

Two-thirds of the expenses connected with the competition shall be defrayed by the Government and one-third by the interested associations, in cooperation with the competing members.

SEC. 21. The amount of 20,000 kroner ($5,360) provided for in section 1, paragraph 13, may be expended by the minister of agriculture in publishing herd books kept by the cooperative Danish agricultural associations; and if the whole amount should not be expended for that purpose, then, on the recommendation of the interested common-management association, a portion of it may be expended for promoting by other means the keeping of herd books for cows by the agricultural associations or the common managements of breeding associations.

SEC. 22. The amount provided for in section 1, paragraph 14, for association experts shall be distributed by the minister of agriculture in the proportion there named for salaries to experts for one or more breeding associations and common managements of cow-test associations.

The government aid shall be subject to recommendation from the common-management association of the province.

The associations or the common managements shall take care that the experts render an annual report, according to further directions from the minister of agriculture, illustrating the work of the experts, and that they take part in the combined meetings of government and association experts called by the secretary.

SEC. 23. With the permission of the minister of agriculture, and on terms fixed by him, on recommendation of the interested common-management association, associations working for the improvement of the breed may hold voluntary public auctions for the sale of breeding animals without the interference of the director of auctions and without paying fees.

## FORM OF CONTRACT USED IN THE PURCHASE OF BULLS.

The following contract is this day made in regard to the bull____________
(Name of bull.)

owned by______________________________and dropped__________________________
(Name of owner.) (Day and year.)

at________________________by_______________________________________________
(Place of birth.) (Dam's name and number.)

This contract is made on the following conditions:

SECTION 1. The seller is to deliver the bull at his own expense and risk, at

___________________________________________________________________________
(Time and place of delivery must be definitely agreed on.)

SEC. 2. At the time of the delivery of the bull the seller will furnish to the buyer:

(*a*) The pedigree of the bull. If the seller has himself reared the bull, he guarantees by his signature on the pedigree the accuracy of the information therein contained. If he has not reared the bull himself, the accuracy of the pedigree must be attested in such manner as the buyer agrees to when the bargain is made.

(*b*) A veterinarian's certificate of the health of the bull at time of delivery, in which it must be specially noted that the tuberculin test has been applied, with favorable outcome. If there is anything lacking in the bull's condition of health, and the buyer is for that reason unwilling to accept the bull, this contract shall become void and neither of the contracting parties shall have any claim against the other.

SEC. 3. The seller guarantees that the bull is willing to serve and able to get calves. If the bull, in spite of proper care, proves to be, in the judgment of the buyer, not sufficiently able to serve and get offspring the first year, the seller will take the bull back again and refund two-thirds of the sum received in accordance with section 4, A, of this contract, and all the conditional payments described in section 4, B, shall thereupon be canceled.

SEC. 4. The purchase price is agreed upon as follows:

A. When the bull is delivered the buyer shall pay ——— kroner.

B. In addition, the buyer shall pay upon the conditions named below the following amounts (conditional payments):

(*a*) If there are found amongst the cows served by this bull not over —— per cent of farrow cows in any one of the first ——— years, then the buyer shall pay ——— kroner for that year; and this clause shall hold good for each separate year of the number of years specified.

(*b*) If the bull is awarded first-class recognition money[a] at the cooperative shows of the island of Funen, the buyer shall pay ——— kroner.

(*c*) If the bull is awarded first, second, or third premium at the government show for bulls in the year ——, the buyer shall pay ——— kroner. (The year following the show indicated in (*d*), next paragraph.)

(*d*) If, on the first occasion when offspring of this bull is exhibited at a government bull show, the bull is awarded an offspring premium of at least second class, first degree, the buyer shall pay ——— kroner.

The conditional payments agreed upon under (*a*) shall be due without notice every year on the first day of October, beginning with October 1, ——. The amounts agreed upon under (*b*), (*c*), and (*d*) shall likewise be due without notice eight days after the above-mentioned recognition money[a] or premiums are awarded to the bull.

All payments shall be made at the residence of the seller, or at any other place which he may designate in this country, without expense to the seller.

SEC. 5. The buyer shall exhibit the bull at the shows named in section 4, unless prevented by ill health on the part of the bull, which must be certified by a veterinarian. In case the bull's ill health prevents exhibiting him, all conditional payments provided for in section 4, B, shall be suspended, but the obligation nevertheless remains upon the buyer if the bull in that year wins any of the awards mentioned in section 4, (*b*) and (*c*).

Should the buyer neglect his obligation to exhibit the bull as agreed, he shall be bound nevertheless to make the payments agreed upon in section 4, (*b*) and (*c*), when they become due.

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[a] See p. 16.

SEC. 6. The buyer shall keep the bull in proper condition of feed for breeding purposes, and give him in all respects good and reasonable care, and keep him covered by life and accident insurance to the amount of his full value.

SEC. 7. Should it be shown that the seller has delivered to the buyer an incorrect pedigree or a false veterinarian's certificate, or that the seller has in any other way given to the buyer false information about the bull, the buyer may annul the contract, and the seller (even if he has acted in good faith) shall be bound to take back the bull and refund the money he has received in accordance with section 4, A; and, furthermore, must pay the buyer for stable room, feed, and care an allowance of ——— kroner for every day which has passed since the delivery of the bull to the buyer until his return delivery to the seller; and neither of the parties shall thereafter have any further claim upon the other.

If the seller knowingly furnishes a false pedigree, veterinarian's certificate, or other information, the buyer may annul the contract, and the seller shall not only refund the sum received according to section 4, A, and reimburse the buyer for stabling, feed, and care, as provided in the first paragraph of this section, but he shall moreover pay the buyer damages to the extent of 1,000 kroner.

SEC. 8. Should the seller fail to fulfill this contract, by not delivering the bull, or by not delivering him at the time and place agreed on, even if such failure be not the fault of the seller, the buyer shall have the option of demanding that the contract be fulfilled or annulling the contract. In either case the buyer shall have the right to demand damages for any loss suffered by such nonfulfillment, and particularly for traveling expenses, loss of time, and hotel bills, incurred in the trip to and from the place of delivery. Should the seller refuse to deliver the bull, or be unable to do so (for instance, by reason of having sold him to some other party), he shall be bound to pay damages in the minimum amount of 200 kroner, and more if the buyer's loss shall actually amount to more.

SEC. 9. Should the buyer be deprived of the bull (by the operation of this contract or by nonfulfillment of the contract on the part of the seller), then the seller, even if he has acted in good faith, shall be bound to refund all money received, and furthermore to pay damages of at least ——— kroner.

If the seller has known in advance that the bull would not be available, he shall, besides refunding all money received, be bound to pay damages of at least 1,000 kroner.

SEC. 10. Should either party refuse or neglect to fulfill the provisions of this contract (including section 9), he shall be bound, whether with or without suit at law, to pay all expenses of collection, including attorneys' and collectors' fees, traveling expenses, and other expenses of collection, even if the amount of the claim should be less than 200 kroner. In regard to this the provisions of the law of August 6, 1824, are expressly waived. The violator shall in addition pay interest on said sums which are to be paid or refunded by him, at the rate of 6 per cent per annum, which interest, on the amounts agreed upon in section 4, is to be calculated from the day when such amounts become due, and on other amounts from the date of the first demand.

-----------------------------------
(Place and date.)

-----------------------------------
(Signature of seller.)

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(Signature of buyer.)

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Issued June 14, 1911.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF ANIMAL INDUSTRY.—BULLETIN 130.
A. D. MELVIN, CHIEF OF BUREAU.

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# STUDIES ON THE BIOLOGY OF THE TEXAS-FEVER TICK.

BY

H. W. GRAYBILL,
*Assistant Zoologist, Zoological Division,
Bureau of Animal Industry.*

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1911.

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# LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Animal Industry,
*Washington, D. C., September 28, 1910.*

Sir: I have the honor to transmit for publication the accompanying manuscript entitled "Studies on the Biology of the Texas-fever Tick," by H. W. Graybill, assistant zoologist in the Zoological Division of this bureau.

A large number of publications have been issued from time to time regarding the investigations of this bureau concerning the Texas-fever tick and its disastrous effect upon the cattle industry of the South, and the extermination of the parasite has in recent years been vigorously pushed both by the Federal Government and the several States involved. In order that this work of extermination may be the more intelligently and successfully carried out it is necessary that it should be based upon the most accurate knowledge possible of the life history, habits, etc., of the tick. Accordingly the experiments herein described were projected in order to add further information relative to certain biological features of the tick which may have a bearing upon the eradication work. The experiments were carried out in cooperation with the veterinary department of the Alabama Polytechnic Institute, at Auburn, Ala.

I recommend that the paper be published in the bulletin series of this bureau.

Respectfully,

A. D. Melvin,
*Chief of Bureau.*

Hon. James Wilson,
*Secretary of Agriculture.*

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# STUDIES ON THE BIOLOGY OF THE TEXAS-FEVER TICK.

## INTRODUCTION.

The eradication of the cattle tick (*Margaropus annulatus*) from the States below the quarantine line has been shown to be entirely feasible as a result of the work carried on during the past five years by the Bureau of Animal Industry in cooperation with the State authorities. The work of extermination must, obviously, be preceded by and based upon a knowledge of the life history of the tick, its habits, and the manner in which it is affected by climatic and other environmental conditions.

In order to supply possibly useful data relative to the biology of the tick, additional to that already collected by different observers, a series of investigations was arranged for and carried out under cooperation between the Zoological Division of this bureau and the veterinary department of the Alabama Polytechnic Institute at Auburn, Ala. In the observational part of these investigations, the results of which are recorded in the present paper, the writer was assisted by Mr. W. M. Lewallen. Some of the results of the work at Auburn have been briefly mentioned in an earlier paper (Graybill, 1909)[10].[a]

## HISTORICAL.

Up to the time that Dr. Cooper Curtice[2] (1891) of this bureau established the fundamental facts in the life history of the cattle tick it was commonly assumed that the life history of this species corresponded to that of certain other ticks, which fall from their host before shedding their skins in transforming from one stage to another. Curtice, however, showed that the cattle tick remains on the host from the time it attaches as a larva until it falls as an engorged female to deposit its eggs, and established other facts relative to the duration of some of the periods in the life cycle and the changes in structure occurring at the time of the first and second molts, which were supplemented in a second paper[3] (1892) by further data concerning the life history, habits, and structure of the tick. Smith and Kilborne[22] (1893), who were the first to demonstrate and prove the connection between the tick and Texas fever, published a number of important facts on the biology of this parasite, and Schroeder[18, 19] (1900 and 1907) and Schroeder and Cotton[20, 21] (1900 and 1907) in several articles issued by this bureau have presented considerable data bearing on the life history of the tick and its relationship to the disease which it transmits. Curtice[5] (1896) was among the first to urge the undertaking of eradication measures, and (1897)[6] was the first to show how cattle could be freed from ticks by rotation methods. Doctor Curtice's work in North Carolina, continued by Dr. Tait Butler, clearly demonstrated at an early date the feasibility of tick eradication, which has been fully confirmed by the experience of the more extensive campaign now under way in various parts of the tick-infested area.

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[a] Citations to literature are given in bibliography on page 38.

Several investigators connected with State experiment stations have studied the tick with reference to its life history. Dinwiddie[8] (1892), of the Arkansas Experiment Station, was an early investigator, who more recently (1908)[9] has published further observations. Morgan (in Dalrymple, Morgan, and Dodson,[7] 1898) reported investigations conducted in Louisiana having to do with various stages of the tick, especially with regard to the influence of heat, cold, and light and the effects of water upon the tick and its eggs. Later the same author[14, 15] (1903, 1905) discussed and emphasized the practicability of freeing cattle and pastures of ticks by following pasture-rotation methods based upon known facts in the life history.

Newell and Dougherty[16] (1906), of the State Crop Pest Commission of Louisiana, made a comprehensive study of various periods in the life cycle, obtaining valuable data on the duration of the incubation period and the vitality of the larvæ, at different times of the year. Their work was conducted at Baton Rouge, La., and they formulated a pasture-rotation method for ridding cattle and farms of ticks, adapted to conditions prevailing in Louisiana. Cotton[1] (1908), of the Tennessee Experiment Station, has published life-history notes based on investigations conducted at Knoxville, Tenn., and has suggested a number of rotation methods for tick eradication.

Recently the Bureau of Entomology of this department has undertaken life-history studies of the tick and has issued Bulletin 72, by Hunter and Hooker[12] (1907), in which are incorporated the results of comprehensive investigations conducted by these authors at Dallas, Tex. The results obtained by these investigators are confirmatory of the earlier work of the Bureau of Animal Industry and other observers, and in addition have largely increased our knowledge of the biology of the tick, supplying data concerning all stages of development, time required for the completion of these stages at different seasons of the year, and the influence of variations in environment, together with suggestions for the practical application of the information given.

## METHODS OF STUDY.

The plan pursued in determining the incubation period of eggs and the longevity of seed ticks in the investigations at Auburn was essentially that followed by Newell and Dougherty[16] (1906). A number of engorged females were collected at the beginning of each month. After oviposition began the eggs laid by each tick were removed at the end of every 24 hours. After they were counted each lot was placed in an incubation tube marked with the date when removed and a number indicating the tick which deposited them. Careful observations were made on the tubes and a record was kept of the time when the eggs in each tube began to hatch and when the hatching was completed, also when the larvæ began to die and when all of them were dead.

At the outset of the work the incubation tubes used were test tubes of the type employed in bacteriological work. These were filled half full of moist sand. A cardboard disk cut so as to fit the tube was pressed down on the sand. On top of this was placed a small cube of cork, and on the latter was placed another disk similar to the first. The eggs were placed on the upper disk. It was found necessary to use these disks in order to prevent the eggs and seed ticks from becoming mixed with the sand, which would have rendered observation very difficult and also would have made the counting of the unhatched eggs and dead seed ticks, for the purpose of determining the percentage of eggs hatching, an almost impossible task. Furthermore, if only one disk is used the development of the eggs is frequently endangered by the growth of mold. When the two are used, separated in the manner indicated, mold frequently grows on the lower one, but does not often attack the upper one in such a manner as to endanger the eggs.

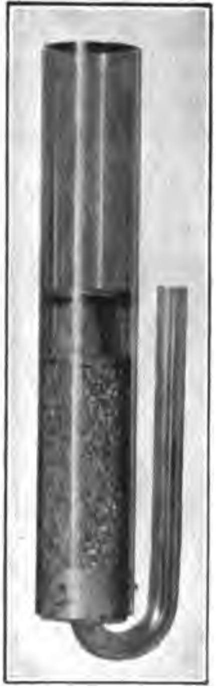
FIG. 1.—Vertical tube used for incubating eggs of ticks.

These tubes, however, were not found entirely satisfactory on account of the fact that there was no practicable way of adding more water to the sand and thus keeping the tube supplied with moisture. To obviate this defect a new tube was devised which was found very satisfactory in most respects (see fig. 1). It is so constructed that it is possible to add water to the sand at any time. The new tubes are made of glass cylinders 11.5 cm. long and about 20 mm. in outside diameter. One end of the cylinder is closed by a cork, pierced in the middle by a hole about 5 mm. in diameter. Into this opening is fitted one arm of a piece of glass tubing bent in the form of a hook. This arm should be long enough to pass through the cork and the bend should be just so broad that the long arm runs up close to the outside of the glass cylinder. The long arm should reach to about the middle of the tube. Water is added through this portion of the tubing. The cardboard disks are arranged in the same manner as in the test tubes previously described, the only modification necessary being to pierce the disks with a needle in order to permit the escape of air from below upward when water is added. In case the short arm of the tubing becomes clogged with sand the tubing is easily removed and flushed out with water. The incubation tubes were closed on top by means of muslin held in place by rubber bands. Cheese cloth is not satisfactory for this purpose, being so loosely woven that the larvæ escape through the openings.

During the course of the work a much simpler method than the above for obtaining records on the nonparasitic stages of the tick was devised. In this method a horizontal tube is used (see fig. 2). This is made of a glass cylinder like that described above. A cork is inserted in one end. On the bottom of the cork a rectangular piece of cardboard is fastened so that one of its long sides projects a little beyond the edge of the cork and serves as a support for the tube, preventing it rolling from side to side. The tube contains a tray constructed as follows: A rectangular piece of rather thick paper, with a width equal to one-half the inside circumference of the tube and a length equal to the internal length of the tube, is provided for the bottom and sides. The ends are made of thin disks of cork having a diameter a little less than the internal diameter of the tube. The rectangular piece of paper is rolled into a half cylinder and the cork ends are pinned or glued into position, each tilting a little toward the other. One of the disks is placed some little distance from the end of the tray, a fingerhold being thus afforded for withdrawing it from the tube. The end of the tube is covered with a piece of muslin.

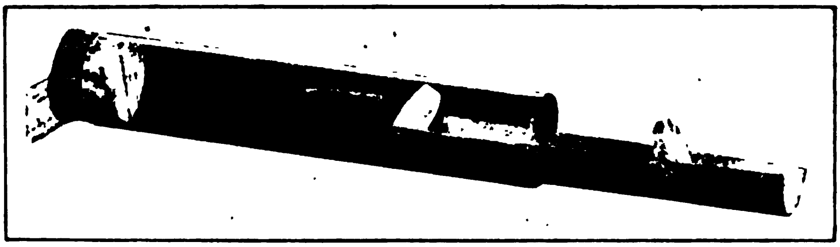

FIG. 2.—Horizontal tube for incubating eggs of ticks.

This particular form of horizontal tube was kept when in use beneath a bell jar supplied with moisture. Another variety with sand in the end next the cork and fitted with a piece of glass tubing for the addition of water, as in the vertical incubation tubes, was also used. These latter tubes furnished conditions practically identical with those in the vertical tubes. Various modifications of these horizontal tubes were used, some being made of ordinary test tubes, but they are hardly of sufficient importance to be described here.

The method of using the horizontal tube is as follows: An engorged female is placed in the tray, which is put in the tube. The tilted ends prevent the tick from crawling up. After oviposition begins the tick moves slowly backward, leaving a long mass of eggs in front of it. When oviposition is nearly completed the female is removed from the eggs to the opposite end of the tray, so as to facilitate observation of the remainder of the process. The newly laid eggs are removed from her each day and placed at the end of the egg mass until oviposition is completed. The hatching proceeds along the mass of eggs until the last hatch, unless, as sometimes happens, there is a displacement of the eggs. The dates when the female was collected, when oviposition began and ended, when hatching began and was completed, and when the first and the last larvæ died are recorded. This method requires such a small amount of time daily in attending to the tubes that a very large number of ticks can be kept under observation at one time and under various conditions.

For the purpose of checking the results obtained in the tubes indoors, experiments were conducted outside in sunny and shady places presenting ordinary pasture conditions. In these experiments small plots in a pasture were used (fig. 3). Each plot consisted of an area 2 feet square inclosed by boards 3 inches wide set edgewise. In the center of the plot an ordinary cigar box with the lid and bottom removed was sunk halfway into the turf. This was done so as to confine the female ticks and thus facilitate observation on them. The box was provided with a cover made of screen wire, which, during the progress of the experiment was covered over with dead leaves or other litter. The plots were protected from surface drainage by properly arranged ditches. Each was surrounded by a fence of wire netting to keep out animals. There were two series of these plots, one in a place shaded by trees for a part of the day and the other in an unshaded place.

The indoor experiments were conducted in an unheated room with the windows open at all times as high as was practicable. The temperature and humidity were thus made to correspond very closely to outdoor conditions.

The experiments in the plots were run parallel with the indoor experiments Usually two plots were started at the beginning of each month. Ordinarily 10 engorged ticks were confined in the box described above and observations were continued on each plot until it became free of seed ticks.

## PERIODS OF THE NONPARASITIC PORTION OF DEVELOPMENT.

The various periods in the nonparasitic portion of the development of the tick which will receive consideration in the following pages are, the preoviposition period, the oviposition period, the incubation period, the hatching period, and the longevity of the larvæ; also the entire period from the time the female drops until all the larvæ are dead. Unless otherwise specified the records given hereafter refer to the experiments in the vertical tubes.

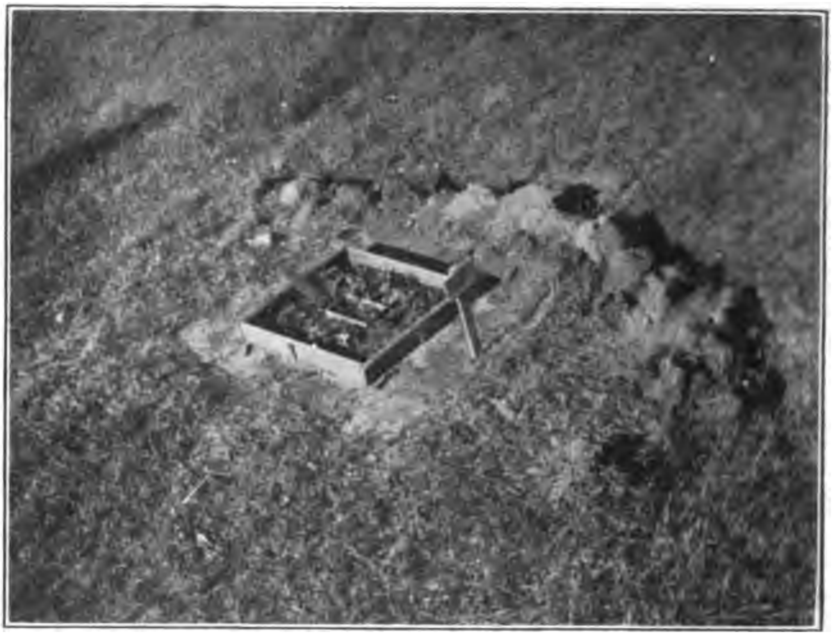

FIG. 3.—Arrangement of field plot for incubating tick eggs under outdoor conditions.

### THE PREOVIPOSITION PERIOD.

This period, so named by Hunter and Hooker[12] (1907, p. 14), extends from the time the female tick drops until she begins to oviposit. Its duration was found to vary greatly for the different months of the year, depending largely on the temperature. The average length of the period, as shown in the following tables, ranged from 3 to 49.3 days. The maximum period observed was 98 days and the minimum 1 day. The latter is not included in the tables, as it was observed outside the course of the regular experiments. It occurred in the case of a moderate-sized tick collected April 29, 1908, which had been placed in a flask along with some others.

During the preoviposition period the ticks under observation were kept either in petri dishes, the bottoms of which were lined with paper, in pasteboard boxes, or in horizontal tubes. The results obtained relative to the preoviposition period, arranged according to the months during which the ticks were collected, are given in the following tables:

*Preoviposition period—Range and average length of periods.*

VERTICAL-TUBE EXPERIMENTS.

| Date ticks were collected. | Number of ticks. | Range of periods. | Average of periods. | Date ticks were collected. | Number of ticks. | Range of periods. | Average of periods. |
|---|---|---|---|---|---|---|---|
| 1907. | | *Days.* | *Days.* | 1908. | | *Days.* | *Days.* |
| June 1 | 7 | 6 to 9 | 7 | Jan. 1, 29, and 30 | 5 | 34 to 63 | 41.2 |
| July 1 | 7 | 3 to 4 | 3.9 | Feb. 3, 4, 27, and 28. | 5 | 8 to 36 | 22.2 |
| Aug. 1 and 31 | 14 | 2 to 4 | 3.1 | Mar. 26 and 29. | 9 | 4 to 8 | 5.2 |
| Oct. 1 | 7 | 4 to 6 | 4.3 | Apr. 29 | 14 | 4 to 7 | 5.9 |
| Nov. 1 and 30 | 11 | 7 to 98 | 30.5 | | | | |
| Dec. 29 | 3 | 39 to 63 | 49.3 | | | | |

HORIZONTAL-TUBE EXPERIMENTS.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1907. | | | | 1908. | | | |
| Aug. 31 | 4 | 3 | 3 | Feb. 3, 24, 27, and 28. | 9 | 10 to 33 | 18.3 |
| Oct. 1 | 4 | 4 | 4 | Mar. 1, 3, 23, and 25. | 7 | 5 to 11 | 7 |
| Nov. 1 and 26 | 5 | 9 to 33 | 18.2 | Apr. 29 and 30. | 10 | 5 to 8 | 6.5 |
| Dec. 25 | 2 | 27 to 33 | 30 | May 1 | 6 | 5 to 9 | 6.1 |

In both tables it is seen that the highest average is for the month of December and the lowest for the month of August.

## THE OVIPOSITION PERIOD.

The duration of this period depends on the temperature, and to a less degree on a number of other things, such as state of engorgement, number of eggs laid, etc. The ticks used were always good specimens, as near complete engorgement as it was practicable to obtain. The average oviposition period for different months of the year, as shown in the following table, ranged from 8.3 days for June, 1907, to 127.5 days for November of the same year. The maximum period noted was 152 days and the minimum 3 days, observed in the case of ticks which began ovipositing in November and June, respectively.

*Oviposition period—Range and average length of periods.*

VERTICAL-TUBE EXPERIMENTS.

| Month oviposition began. | Number of ticks. | Range of periods. | Average of periods. | Month oviposition began. | Number of ticks. | Range of periods. | Average of periods. |
|---|---|---|---|---|---|---|---|
| 1907. | | *Days.* | *Days.* | 1908. | | *Days.* | *Days.* |
| June | 7 | 3 to 14 | 8.3 | January | 2 | 54 to 87 | 70.5 |
| July | 7 | 4 to 20 | 12.9 | February | 3 | 37 to 63 | 46.7 |
| August | 7 | 12 to 19 | 15.6 | March | 14 | 17 to 43 | 30.2 |
| September | 6 | 14 to 19 | 16.5 | April | 7 | 14 to 35 | 24.9 |
| October | 7 | 21 to 37 | 32.9 | May | 14 | 19 to 27 | 22.8 |
| November | 7 | 78 to 151 | 98.4 | | | | |

HORIZONTAL-TUBE EXPERIMENTS.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1907. | | | | 1908. | | | |
| September | 6 | 9 to 21 | 15 | January | 4 | 73 to 91 | 79 |
| October | 4 | 22 to 37 | 29.7 | March | 16 | 26 to 49 | 34.6 |
| November | 4 | 83 to 152 | 127.5 | April | 1 | 24 | 24 |
| | | | | May | 16 | 15 to 24 | 20.8 |

## INCUBATION PERIOD.

The duration of this period depends principally on the temperature. It was found to range from 19 days in the summer to 180 days beginning in the fall. Low temperatures not only retard but even may arrest temporarily or permanently the development of the eggs. Moisture, although necessary to development, has but a small influence, if any, on the rate at which this takes place.

The conditions essential to the development and eventual hatching of eggs are a proper supply of moisture and a favorable temperature. All that is required in the way of moisture is a sufficient atmospheric humidity to prevent eggs losing moisture by evaporation. With regard to temperature it may be said that the maximum, minimum, and optimum temperatures for development of the eggs have not been determined. Hunter and Hooker[13] (1907) have assumed 43° F. as the minimum, but this has not yet been verified by experiment. Eggs are frequently killed by the low temperatures occurring during the winter months, although those that have been incubated for a time are less susceptible to the ill effects of cold than those newly laid.

As has been previously stated, the eggs were removed from each female tick at the end of every 24 hours and placed in vertical tubes. A record was kept of the date each lot was laid, the date the eggs began to hatch, and the date they completed hatching. The latter date is, however, only approximately correct, since it is not possible to determine accurately when all the eggs of a lot have hatched, on account of the fact that some eggs having all the marks of viability frequently fail to hatch. By using the three dates just mentioned, two incubation periods were determined for each lot of eggs, which are referred to here as the maximum and minimum. The range of the incubation periods of the eggs laid by each tick is given in Table 1 of the Appendix. The range of the minimum incubation periods and the averages for each month, from June, 1907, to May, 1908, are given in the following table:

*Incubation period—Range and average length of minimum incubation periods.*

| Month eggs deposited. | Number of lots. | Range of periods. | Average of periods. | Month eggs deposited. | Number of lots. | Range of periods. | Average of periods. |
|---|---|---|---|---|---|---|---|
| 1907. | | *Days.* | *Days.* | 1908. | | *Days.* | *Days.* |
| June | 60 | 22 to 27 | 24.5 | February | 1 | 80 | 80 |
| July | 82 | 19 to 24 | 20.5 | March | 270 | 46 to 63 | 52.7 |
| August | 90 | 19 to 24 | 21.2 | April | 197 | 36 to 53 | 43.6 |
| September | 81 | 28 to 64 | 35.9 | May | 279 | 23 to 34 | 26.3 |
| October | 145 | 165 to 180 | 173.1 | | | | |
| November | 31 | 148 to 170 | 155.5 | | | | |
| December | 7 | 117 to 139 | 128.6 | | | | |

From the above table it is seen the averages increase from July to October, 1907, and decrease from November, 1907, to May, 1908. The average for June, 1907, being higher than for July, which marks the beginning of the increase, indicates that the average for the latter month is the lowest that would have been obtained had the experiments covered the first part of the year. The longest minimum incubation period was 180 days and the shortest 19 days.

### HATCHING PERIOD.

The eggs deposited by a female do not all hatch at the same time, but approximately in the sequence in which they are laid. The time required for all of the eggs to hatch after hatching begins may be called the hatching period. This may be considered normal in length only when approximately all the eggs hatch or a goodly portion of the first and the last eggs deposited hatch. Because of the low percentage of eggs which hatched in the case of some of the ticks the hatching periods of these have no significance and are, therefore, not considered in the following table. The average period for different months of the year is seen in the following table to range from 10.6 days for July, 1907, to 36 days for October of the same year. The maximum period observed was 49 days and the minimum 4 days. The eggs of all the ticks collected previous to October, 1907, hatched in the fall and those laid by ticks collected October 1 did not begin to hatch until the following March, and of course the eggs of those collected during November and the succeeding months did not begin to hatch until later, consequently no hatching periods were obtained during the colder part of the year. It is therefore evident that the maximum period observed is much less than might occur with a slightly different winter season, or if ticks had been collected on such a date that the hatching of the eggs would have begun in the fall and not been completed until the following spring.

*Hatching period—Range and average length of periods.*

VERTICAL-TUBE EXPERIMENTS.

| Month hatching began. | Number of ticks. | Range of periods. | Average of periods. | Month hatching began. | Number of ticks. | Range of periods. | Average of periods. |
|---|---|---|---|---|---|---|---|
| 1907. | | *Days.* | *Days.* | 1908. | | *Days.* | *Days.* |
| July | 14 | 4 to 17 | 10.6 | March | 6 | 21 to 31 | 26 |
| August | 7 | 8 to 16 | 13.4 | April | 8 | 16 to 27 | 23.6 |
| October | 6 | 31 to 49 | 36 | May | 11 | 12 to 18 | 14.3 |
| | | | | June | 14 | 12 to 22 | 17.2 |

HORIZONTAL-TUBE EXPERIMENTS.

| Month hatching began. | Number of ticks. | Range of periods. | Average of periods. | Month hatching began. | Number of ticks. | Range of periods. | Average of periods. |
|---|---|---|---|---|---|---|---|
| 1907. | | | | 1908. | | | |
| October | 5 | 18 to 37 | 23.6 | March | 3 | 21 to 24 | 22.3 |
| | | | | April | 7 | 10 to 27 | 21.3 |
| | | | | May | 12 | 9 to 21 | 15.6 |
| | | | | June | 16 | 5 to 18 | 11.4 |

## LONGEVITY PERIOD.

The longevity of the larvæ depends on individual vitality, humidity, and temperature. Some larvæ do not have sufficient vitality to disengage themselves from the ruptured eggshell and die partly inclosed within it. This was especially noticeable in eggs laid during the winter, so it would seem that a low temperature may affect the vitality of unhatched larvæ. Other larvæ die very soon after emerging. Cold prolongs longevity because of the fact that the tick remains quiescent, and as a result the body fluids and nourishment are conserved. A high relative humidity prolongs longevity by hindering the loss of body moisture by evaporation and also by causing the ticks to remain more quiescent than when the air is dry. In addition to these factors certain instincts of the larvæ promote longevity. They respond negatively to light. In sunny places they collect on the under or the shady side of leaves, stems, and other objects, thus protecting themselves from the direct heat of the sun. They also manifest an interesting adaptation in being able to detect the presence of a possible host at a distance of several feet. This fact was observed and verified many times with larvæ located on plots outdoors. Larvæ that were quiescent when one approached within 3 or 4 feet of a plot, in the course of a half to several minutes became very active and extended their front legs upward in a divergent position, waving them violently in an evident attempt to seize onto a host. This instinct is probably dependent on an olfactory sense resident in the organ of Haller located on the tarsi of the first pair of legs. It may possibly be connected with a thermal sense, but this hardly seems probable, since the reaction was found to occur just as readily on extremely warm days as on cool days. The response takes place more quickly when one is located on the windward side of the larvæ. This instinct permits the larvæ to remain quiescent without reducing their chances for reaching a host. The periods of inactivity conserve the vitality of the tick and consequently must prolong longevity.

In making observations on the longevity, the date when the larvæ in each tube began to die and when all of them were dead was recorded. In determining the longevity of the larvæ resulting from each lot of eggs, the date when the eggs began to hatch, together with the two dates just mentioned above, were used, thus obtaining a minimum and maximum longevity period.

The range of the maximum and the minimum longevity and the average of the former for lots of larvæ hatched during the different months of the year, are given in the following table:

*Longevity period—Range of maximum and minimum longevity and average of maximum longevity.*

| Month hatched. | Number of lots. | Range of minimum longevity periods. | Range of maximum longevity periods. | Average of maximum longevity periods. | Month hatched. | Number of lots. | Range of minimum longevity periods. | Range of maximum longevity periods. | Average of maximum longevity periods. |
|---|---|---|---|---|---|---|---|---|---|
| 1907. | | *Days.* | *Days.* | *Days.* | 1908. | | *Days.* | *Days.* | *Days.* |
| July | 106 | 4 to 39 | 7 to 85 | 38.6 | March | 24 | 5 to 22 | 57 to 94 | 73.2 |
| August | 83 | 9 to 36 | 9 to 192 | 84.9 | April | 189 | 3 to 63 | 19 to 99 | 65.1 |
| September | 44 | 4 to 35 | 9 to 190 | 56.2 | May | 406 | 2 to 57 | 4 to 103 | 62.3 |
| October | 75 | 5 to 163 | 30 to 234 | 167.4 | June | 380 | 4 to 55 | 8 to 128 | 65.1 |
| November | 5 | 21 to 70 | 33 to 135 | 85 | | | | | |

The eggs which hatched during July, August, and September were kept in tubes which were not supplied with water other than that originally added to the sand. This may account for the rather low averages for July and September. It is noted that the highest average is for the lots hatched during the month of October, and this month also gave the longest maximum period; the lowest average is for July, which likewise gave the shortest maximum longevity period.

## TOTAL TIME OF NONPARASITIC DEVELOPMENT.

The period of nonparasitic development is the time from the date the female drops until all the resulting larvæ are dead. It is of prime importance from a practical standpoint, since it indicates the length of time animals must be kept out of an infested pasture in order for it to become tick free. A summary of the data on this period is given in the table following.

*Total time from dropping of female until all resulting larvæ are dead.*

| Date engorged females were collected. | Number of engorged. females. | Range of entire-time periods. | Average of periods. | Date engorged females were collected. | Number of engorged females. | Range of entire-time periods. | Average of periods. |
|---|---|---|---|---|---|---|---|
| | | *Days.* | *Days.* | | | *Days.* | *Days.* |
| June 1, 1907...... | 7 | 79 to 100 | 86.9 | | | | |
| July 1, 1907...... | 7 | 82 to 112 | 101 | Dec. 29, 1907, to Jan. 1, 1908..... | 3 | 181 to 207 | 196.3 |
| Aug. 1, 1907...... | 7 | 172 to 221 | 199.6 | | | | |
| Aug. 31, 1907..... | 6 | 230 to 272 | 250.7 | Jan. 29 to Feb. 4, 1908........... | 7 | 156 to 189 | 173.1 |
| Oct. 1, 1907...... | 7 | 276 to 288 | 279.6 | Feb. 27 to 28, 1908. | 2 | 143 to 162 | 152.1 |
| Nov. 1, 1907...... | 7 | 200 to 253 | 232.7 | Mar. 26 to 29, 1908. | 9 | 144 to 161 | 152.1 |
| Nov. 30, 1907..... | 3 | 187 to 249 | 217 | Apr. 29, 1908..... | 14 | 122 to 173 | 142.8 |

In the above table the averages are seen to increase from 86.9 days for June, to 279.6 days for October, 1907, and to decrease from the latter month for the rest of the time. The maximum periods likewise increased from 100 days for June to 288 days for October and thereafter steadily decreased each month until March.

## NUMBER OF EGGS LAID AND PERCENTAGE HATCHED.

The eggs laid by each female (except in the case of controls, which are referred to below) were counted when they were removed and before they were placed in the incubation tubes. And furthermore, after all the larvæ in each tube had perished, the unhatched eggs were removed and counted. The purpose of this was twofold, first to determine the number of eggs laid by a female, and, second, to calculate the percentage of eggs which hatched. In the case of certain ticks, the eggs of which were left uncounted for the purpose of serving as controls on the counted eggs, it was necessary, in addition to counting the unhatched eggs, to count the dead larvæ in order to determine the number of eggs laid. The data obtained are given in columns 3 and 11, respectively, of Table 1, Appendix. A summary showing the range in the number of eggs laid by each lot of ticks, the average number of eggs laid and per cent hatched, is presented in the following table:

*Egg laying and hatching—Total and average number of eggs laid and per cent hatched.*

| Date ticks collected. | Number of ticks. | Eggs laid. | Average eggs laid. | Eggs hatched. | Date ticks collected. | Number of ticks. | Eggs laid. | Average eggs laid. | Eggs hatched |
|---|---|---|---|---|---|---|---|---|---|
| | | *Number.* | *Number* | *Per ct.* | | | *Number.* | *Number* | *Per ct.* |
| June 1, 1907..... | 7 | 630-3,095 | 1,811 | 73-95 | | | | | |
| July 1, 1907..... | 7 | 1,858-3,820 | 2,919 | 90-97 | Dec. 29, 1907, to Jan. 1, 1908... | 4 | 1,970-4,272 | 3,149 | 0-35 |
| Aug 1, 1907..... | 7 | 1,851-3,683 | 2,690 | 90-98 | | | | | |
| Aug 31, 1907.... | 6 | 2,049-2,809 | 2,405 | 57-97 | Jan 29, to Feb. 4, 1908........ | 7 | 806-4,276 | 3,331 | 14-86 |
| Oct 1, 1907...... | 7 | 960-3,385 | 2,563 | 77-92 | Feb. 27-28, 1908. | 2 | 2,302-2,925 | 2,614 | 62-96 |
| Nov 1, 1907..... | 7 | 991-2,961 | 2,129 | 1-7 | Mar. 26-29, 1908. | 9 | 2,680-4,559 | 3,507 | 66-97 |
| Nov 30, 1907.... | 4 | 357-3,207 | 2,173 | 0-18 | Apr. 29, 1908.... | 9 | 3,246-5,105 | 4,089 | 33-98 |

The minimum number of eggs laid was, as the above table indicates, 357, and the maximum number 5,105. The average number ranges from 1,811 to 4,089. The percentage of eggs hatching in the case of ticks collected from November 1, 1907, to January 1, 1908, ranged from 0 to 35, and for the rest of the time from 14 to 98.

In counting the eggs they were placed on white paper and arranged in a long row one egg deep and several eggs wide. In order to injure them as little as possible and reduce the chances of crushing them, small spatulas made of thin paper were used in handling them. The counting was done with the aid of a pocket lens. For the purpose of determining whether the manipulation involved in counting the eggs reduced the percentage that hatched, two ticks in each of the first six sets of experiments were selected as controls, their eggs not being counted. The results are given in the following table:

*Percentage of eggs hatching from counted and uncounted lots.*

| Date ticks collected. | Number of ticks. | Eggs counted or uncounted. | Per cent hatched. | Date ticks collected. | Number of ticks. | Eggs counted or uncounted. | Per cent hatched. |
|---|---|---|---|---|---|---|---|
| 1907. | | | | 1907. | | | |
| June 1 | 5 | Counted | 92.1 | Aug. 31 | 5 | Counted | 79.5 |
| Do | 2 | Uncounted | 84.9 | Do | 1 | Uncounted | 97 |
| July 1 | 5 | Counted | 95.3 | Oct. 1 | 5 | Counted | 85.5 |
| Do | 2 | Uncounted | 95 | Do | 2 | Uncounted | 85.7 |
| Aug. 1 | 5 | Counted | 95.3 | Nov. 1 | 5 | Counted | 3.4 |
| Do | 2 | Uncounted | 95.8 | Do | 2 | Uncounted | 5 |

Two of the above averages for the controls are less and four are more than the corresponding averages for the counted eggs. Disregarding, however, slight differences ranging from 0.2 to 1.6 per cent, which have little significance, the corresponding average may be said to be the same in all except two cases. In one of these the average for the control is 17.5 per cent more and in the other 7.2 per cent less. It seems safe to say from the above results that the manipulation involved in counting, when done with moderate care, does not appreciably lower the per cent of eggs hatching, and that this has not materially affected the percentage of eggs hatched in the course of the present experiments.

## EXPERIMENTS WITH HORIZONTAL TUBES.

The tubes used in these experiments have already been described on page 10 (see fig. 2). Those referred to below as being supplied with moisture were either kept in a moist chamber or were of the type having sand in one end. A summary of the data is given in the table following.

*Summary of the data obtained from the experiments with horizontal tubes.*

| Date ticks were collected. | Preoviposition period. | Oviposition period. | Incubation period. | Hatching period. | Longevity of larvæ. | Conditions of experiment. | Total time from date females were collected to death of larvæ. |
|---|---|---|---|---|---|---|---|
| 1907. | *Days.* | *Days.* | *Days.* | *Days.* | *Days.* | | *Days.* |
| Aug. 31 | 3 | 9 to 17 | 30 to 31 | 18 to 22 | [a] 195 to 217 | Moisture | 229 to 250 |
| Oct. 1 | 4 | 22 to 37 | 165 to 167 | 21 to 24 | 78 to 92 | do | 247 to 261 |
| Nov. 1 | 9 to 20 | 130 to 152 | 167 | 16 | 70 | do | 246 |
| Nov. 26 | 20 to 33 | ([b]) | ........ | ........ | ........ | do | ........ |
| Dec. 25 | 27 to 33 | 74 to 78 | 88 to 94 | 10 to 25 | 62 to 83 | do | 204 |
| 1908. | | | | | | | |
| Feb. 3 | 29 to 33 | 35 to 49 | 53 to 59 | 20 to 27 | 87 to 109 | do | 172 to 194 |
| Feb. 24 to Mar. 3 | 10 to 16 | 30 to 40 | 50 to 56 | 16 to 24 | 71 to 105 | do | 131 to 168 |
| Mar. 23 to 25 | 5 to 6 | 26 to 31 | 43 to 48 | 9 to 15 | 49 to 71 | do | 103 to 121 |
| Apr. 29 to 30 | 5 to 8 | 21 to 24 | 29 to 32 | 5 to 18 | 79 to 111 | do | 114 to 147 |
| May 1 | 5 to 9 | 15 to 21 | 29 to 31 | 6 to 10 | 15 to 17 | No moisture. | 50 to 53 |

[a] After all the eggs had hatched the larvæ were placed on vegetation outdoors.
[b] Only a few eggs were laid, all of which shriveled.

The minimum entire time when the tubes were kept moist occurred in the case of ticks collected March 23 to 25, 1908, and the maximum with the ticks collected October 1, 1907. In the case of the vertical tubes the maximum entire time also fell to the ticks collected October 1. For the purpose of determining the influence of moisture on the duration of the entire time some ticks collected May 1, 1908, were kept in tubes which were not supplied with moisture. Other ticks collected April 29 and 30 were supplied with moisture as usual. The difference in the result is very striking, the duration in the latter case being nearly three times as long as in the former.

## RECORDS OBTAINED FROM THE FIELD PLOTS.

In the indoor experiments the conditions were made to correspond as nearly as possible with those existing outside. It was evident, however, even before the work presented in this bulletin was taken up, that this could only be accomplished in a very imperfect manner and that it would be well to conduct a parallel set of experiments outside under natural conditions for the purpose of checking the indoor experiments. Natural conditions are far from being uniform, however. Even in the same pasture a variety of environments may be present and the duration of the various periods in the life history of the tick be quite different under each. Furthermore, climatic conditions may vary considerably from year to year in the same place. The important thing, however, from a practical standpoint is to determine the environments that will give maximum and minimum periods. An attempt was made to obtain such periods by running two sets of field plots, one on well drained, sunny ground and the other on moist, partly shady ground. The character of the plots and the method of confining the ticks have been described on page 11. In these experiments it was not possible to make notes on individual ticks, and consequently the data are not as complete as those of the indoor work. The data of economic importance are the date the first eggs hatched and the date all the larvæ were dead.

In four of the plots located in the sun, started June 3, July 1, August 1, and August 31, 1907, the engorged ticks were destroyed by small red ants;[a] in two started November 1, 1907, and January 31 to February 1, 1908, eggs were deposited but no larvæ appeared; and in three started November 26 and December 16, 1907, and January 1, 1908, all the females died without ovipositing. In the case of plots located under partly shady conditions, in three of them started on August 31, October 1, and November 1, 1907, eggs were deposited but no larvæ appeared; in two started November 26 and December 16, 1907, all the females died without depositing eggs.

In all the plot experiments started between November 1, 1907, and January 1, 1908, inclusive (see second table below), no larvæ appeared, either for the reason that the females succumbed to the severe weather or that the eggs deposited failed to hatch.

The records of the last three plots located in the sunlight and in the shade furnish an interesting comparison with regard to the influence of environment on the eggs and larvæ. They are given in the following table:

*Influence of environment on eggs and larvæ.*

| In sunlight. | | | In shade. | | |
|---|---|---|---|---|---|
| Date ticks were collected. | Date first eggs hatched | Date all larvæ were dead. | Date ticks were collected. | Date first eggs hatched. | Date all larvæ were dead. |
| 1908. | | | 1908. | | |
| Mar. 1-2 | May 8 | July 31 | Feb. 28-29 | May 18 | Aug. 3 |
| Mar. 27-28 | May 20 | Aug. 8 | Mar. 27 | June 8 | Aug. 23 |
| Apr. 27 | June 5 | July 28 | Apr. 27 | June 18 | Sept. 5 |

Larvæ appeared from 10 to 19 days earlier in the sunny plots than in the shady ones and succumbed 3 to 39 days earlier.

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[a] Specimens of this ant were sent to Prof. W. M. Wheeler, of Harvard University, for identification and found to be one of our small "Thief ants," *Solenopsis molesta* Say, which is common in pastures and fields, where it leads a subterranean life and feeds on larvæ and pupæ of other ants, on sprouting seeds, dead insects, etc.

In the following table a comparison is made of the results obtained in the vertical tubes and in the field plots:

*Comparison of records of vertical tubes and field plots, Auburn, Ala., 1907–8.*

| Vertical tubes. | | | Field plots. | | |
|---|---|---|---|---|---|
| Date females were collected. | Date first eggs hatched. | Date all larvæ were dead. | Date females were collected. | Date first eggs hatched. | Date all larvæ were dead. |
| June 1, 1907 | July 4 | Sept. 9 | June 4, 1907 | July 7 | Aug. 29 |
| July 1, 1907 | July 28 | Oct. 21 | July 1, 1907 | July 29 | Oct. 8 |
| Aug. 1, 1907 | Aug. 27 | Mar. 9 | Aug. 1, 1907 | Aug. 30 | Mar. 27 |
| Aug. 31, 1907 | Oct. 3 | May 29 | Aug. 31, 1907 | (a) | .......... |
| Oct. 1, 1907 | Mar. 19 | July 15 | Oct. 1, 1907 | Apr. 10 | June 8 |
| Nov. 1, 1907 | Apr. 17 | July 11 | Nov. 1, 1907 | (a) | .......... |
| Nov. 30, 1907 | May 4 | Aug. 5 | Nov. 26, 1907 | (b) | .......... |
| | | | Dec. 16, 1907 | (b) | .......... |
| Dec. 29, 1907 to Jan. 1, 1908 | Apr. 28 | July 23 | Jan. 1, 1908 | (b) | .......... |
| Jan. 29 to Feb. 4, 1908 | Apr. 27 | Aug. 11 | Feb. 1 and 2, 1908 | May 14 | July 22 |
| Feb. 27 and 28, 1908 | Apr. 28 | Aug. 7 | Feb. 28 to Mar. 2, 1908 | May 8 | Aug. 3 |
| Mar. 26 to 29, 1908 | May 19 | Sept. 3 | Mar. 27 and 28, 1908 | May 20 | Aug. 23 |
| Apr. 29, 1908 | June 4 | Oct. 19 | Apr. 27, 1908 | June 5 | Sept. 5 |

[a] No larvæ appeared.

[b] All died without ovipositing.

From the above table it will be noted that the period from the collection of the ticks to the time the first eggs hatched in the case of the indoor experiments started June 1 and March 26–29 (33 and 54 days, respectively) is the same as for the corresponding outdoor experiments. In the case of the remaining experiments the time is shorter 1 to 22 days for the indoor than for the outdoor experiments. In all the experiments, except the one begun August 1, the time from the collection of the ticks to the death of all the larvæ was longer by from 5 to 42 days in the indoor than in the corresponding outdoor experiments.

### PER CENT OF FEMALES OVIPOSITING.

The data obtained on this point are not very extensive. In each of the lots of ticks collected on the dates indicated in the second column of Table 1, Appendix, 100 per cent oviposited except in the case of the ticks collected November 30 and December 29, 1907, to January 1, 1908, of which 80 and 33 per cent, respectively, oviposited. Tick No. 27, collected August 31, 1907, deposited but 39 eggs, none of which hatched. This tick was very probably abnormal, but the ticks that failed to oviposit were no doubt unfavorably affected by low temperature.

Of the ticks kept in the horizontal tubes only one failed to oviposit. This was collected February 3, 1908. The majority of the engorged females placed in the plots outside during the latter part of the fall and the winter of 1907–8 failed to oviposit. They appeared to succumb as a result of low temperature and excessive moisture. The first indication of abnormality usually noticed was a reddish tinge appearing over the Malpighian tubules, which normally appear as yellow streaks through the integument of the tick. Then the tick began to swell, becoming very tightly distended, the color became dark, and finally, if not punctured by some enemy, the integument ruptured of itself and a sanguineous fluid issued from the opening.

### EFFECT OF IMMERSION IN WATER ON ENGORGED FEMALES.

A number of tests were carried out to determine what effect immersion in water, both before and after the beginning of oviposition, has on engorged females. On May 1, 1908, eight engorged females were placed in separate wide-mouthed bottles and covered with distilled water. All of them died without ovipositing.

The following tests were made in the Zoological Laboratory, Washington, D. C.:

August 11, 1908, 10 engorged females were collected and placed in tap water. All died without ovipositing.

August 13, 9 engorged females (collected August 12) were submerged in normal salt solution. All died without ovipositing.

September 15, 13 engorged females (collected September 10) that had begun to deposit eggs were submerged in tap water. None of them continued to deposit eggs.

September 15, 10 engorged females (collected September 10) that had begun to oviposit were placed in a Petri dish and half covered with tap water. None of them continued to deposit eggs.

September 21, 8 engorged females (collected September 15) that had begun to oviposit were placed in tap water. All died without depositing additional eggs.

The first effect of water on engorged ticks is to cause them to become distended, and later the coloring matter of the blood within the body escapes and colors the water. In some instances the distention of the tick is so great that its form is almost spherical. This was not so pronounced in normal salt solution as in tap water.

Hunter and Hooker [12] (1907) found that females submerged continuously in tap water failed to oviposit. In one experiment, however, they found that two out of five ticks submerged during October for 91½ hours deposited viable eggs, but ticks submerged for 115½ hours failed to deposit eggs.

### THE INFLUENCE OF MOISTURE ON THE INCUBATION PERIOD.

For the purpose of determining what influence moisture might have on the duration of the incubation period, eggs were subjected to different degrees of moisture. The eggs used each day had been deposited by a number of females during the previous 24 hours. Some of the lots were placed in the regular incubation tubes and others in test tubes containing wet sand. In the former case the eggs rested on cardboard that was never more than moist, while in the latter case they rested directly on wet sand. In one instance, referred to below, the eggs of a tick (No. 138, Table 1) were floated on water. This is considered a condition which will furnish a maximum amount of moisture.

In determining the results of the tests the incubation periods of lots of eggs deposited on the same date and kept in regular incubation tubes were averaged, and the same was done in the case of the eggs placed on moist sand. The averages for lots deposited on 12 days during March, 1908, are as follows:

*Average incubation periods of eggs under different moisture conditions.*

| | Mar. 9. | Mar. 10. | Mar. 11. | Mar. 12. | Mar. 13. | Mar. 14. | Mar. 16. | Mar. 17. | Mar. 18. | Mar. 19. | Mar. 20. | Mar. 24. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Days.* | *Days.* | *Days.* | *Days.* | *Days.* | *Days.* | *Days.* | *Days.* | *Days.* | *Days.* | *Days.* | *Days.* |
| On cardboard | 55 | 53 | 54 | 53 | 53 | 52 | 51 | 51 | 53 | 53 | 53 | 51 |
| On moist sand | 51 | 52 | 53 | 52 | 51 | 50 | 50 | 49 | 53 | 51 | 55 | 51 |

It is seen that nine of the averages for eggs kept on moist sand run from one to four days less, two are the same and one is two days more than the corresponding averages for eggs on cardboard. The mean average for the eggs on wet sand is approximately one day less than for those on moist cardboard.

The averages for 169 lots of eggs placed in regular incubation tubes and 101 lots placed on moist sand and on water (82 on moist sand and 19 on water), deposited from May 6 to 26, inclusive, 1908, show the following result: Five of the averages for eggs on moist sand and on water considered together are from one to two days less, thirteen are the same, and three are one day more than the corresponding averages for eggs resting on cardboard. The average for all the lots of eggs on moist sand and water is three-tenths of a day less than for those on cardboard.

From these tests, so far as they go, it appears that an abundance of moisture shortens the incubation period so little that for all practical purposes its influence may be disregarded.

## PERIODS IN THE PARASITIC PORTION OF DEVELOPMENT.

There are three stages in the parasitic portion of the development of the tick, viz, larval, nymphal, and adult. Until the latter stage is reached males and females are not recognizable with certainty. The duration of each of these stages and the duration of a single infestation upon cattle during different portions of the year are of great practical importance. Upon the duration of an infestation depends the time animals must be kept on tick-free fields in order to become free from ticks.

Tick-free animals were infested at nine different times, as indicated in column 1, Table 2, of the Appendix. It was found that the minimum larval period ranged from 5 to 7 days; the minimum nymphal period of females, 9 to 11 days; the adult period, from a minimum of 5 to a maximum of 33 days. The duration of each infestation, as given in the last column of the table, ranged from 30 to 66 days. The lower temperature during the fall and winter retarded the second molt of some of the ticks, prolonging the time that nymphs were present, and increasing the duration of infestation. It seems possible also that the latter result may be partly due to delayed fertilization of the females, which could readily obtain in case the atmospheric temperature was such as to reduce the activity of the males.

The maximum numbers in column 9 of the table (length of nymphal period) indicate the time from the molting of the first larva to the molting of the last nymph, and consequently represent the time that nymphs were present on the animal. This time in all probability is much longer than the nymphal period of any individual tick.

A number of days previous to the second molt it is possible to distinguish male and female nymphs with a fair degree of certainty. The former are somewhat smaller than the latter and also differ slightly in color and shape. The first nymphs to molt are males. The first female nymphs molt from one to several days later. All the male nymphs molt before the last female molts if they originally attached to their host on the same date.

In the infestations made on February 29, April 4, and May 23, after the larvæ had attached themselves a certain number were marked and observed from day to day. The range of the periods observed in these instances follow.

*Length of periods and total duration of parasitic development.*

| Date larvæ applied. | Sex. | Length of larval period. | Length of nymphal period. | Length of adult period. | Duration of parasitic period. |
|---|---|---|---|---|---|
| 1908. | | *Days.* | *Days.* | *Days.* | *Days.* |
| Feb. 29 | Females | 8 to 9 | 10 to 15 | 5 to 13 | 25 to 34 |
| Do | Males | 7 to 9 | 8 to 10 | | |
| Do | (?) | 7 to 14 | | | |
| Apr. 4 | Females | 7 | 9 to 14 | 4 to 9 | 25 to 26 |
| Do | Males | 7 | 8 to 12 | | |
| May 23 | Females | 6 to 7 | 9 to 12 | 6 to 9 | 22 to 25 |
| Do | Males | 5 to 8 | 8 to 13 | | |

Nineteen larvæ were marked in the infestation of February 29. One of theses died previous to the first molt, three disappeared after the first molt, and one female died three days after the second molt. The male located beneath the latter left on the following day. Twenty-six larvæ of the April infestation were marked. Sixteen of these disappeared previous to the first molt, one after the first molt, and one after the second molt. In the infestation of May 23, 23 larvæ were marked. None disappeared previous to the first molt, four disappeared after the first molt, none disappeared after the second molt.

There seems to be no satisfactory explanation for the disappearance of the ticks, particularly those in the larval stage. Of course, ticks shortly after the first and second molt could easily be rubbed off. In comparing the maximum parasitic period in each of the three cases given in the above table with the duration of the same infestations given in Table 2, Appendix, it is noted that all the latter are longer. The difference for the infestation made February 29 is 10 days; for both April 4 and May 23, 12 days. The reason for this great difference is not clear. It may be due to one or several causes, such as larvæ remaining on the cattle for some days without attaching themselves (this has been noticed in several instances) or ticks after the first and second molt not reattaching immediately or becoming dislodged and later reaching the host again.

## OBSERVATIONS ON THE MOVEMENT OF TICKS AFTER THE FIRST AND SECOND MOLT.

Ransom[17] (1906, p. 5) pointed out the fact that *Margaropus annulatus*, though remaining on the host, must reattach itself after the first and second molt just as other species do which drop from their host and molt on the ground. Hunter and Hooker[12] (1907, p. 29) state that repeated careful observations show that they do not actually detach themselves at either molt. As this question has a more or less important bearing on the dissemination of ticks, and also, possibly, the transmission of Texas fever, as pointed out by Ransom[17] (1906), some observations were made along this line. Since the cuticle shed at molting remains attached to the skin of the host for some time thereafter, particularly following the second molt, it is an easy matter to determine whether the rostrum of the tick is embedded at the original point of attachment or elsewhere. The following observations indicate that reattachment may take place after both the first and the second molt. Not many specific observations were recorded with regard to the movement of young females, but general observations such as are recorded for August 7 were made at various times. The nymphs referred to below were marked early in their larval stage by clipping the hair surrounding them and were observed daily.

### CHANGE OF LOCATION AFTER THE FIRST MOLT.

January 10, 1908, one newly molted nymph reattached 6 mm. from original point of attachment of larva.

January 11, three newly molted nymphs reattached 3 to 6 mm. from original point.

May 28, one nymph just molted reattached 3 mm. from original point.

May 29, one nymph just molted reattached 8 mm. from original point.

May 29, two nymphs just molted reattached 2 mm. from original point.

May 29, four nymphs just molted reattached 4 mm. from original point.

May 30, two nymphs just molted reattached 2 mm. from original point.

May 30, six nymphs just molted reattached 4 mm. from original point.

### CHANGE OF LOCATION AFTER SECOND MOLT.

On July 18, 1907, a cow was infested with larvæ. August 7, all the nymphs had molted. No females could be found that had wandered any great distance. In many instances, however, females were found located a fraction of a millimeter to 1 mm. posterior and several millimeters to one side of the place where previously attached.

In the case of a cow infested August 17, 1907, on September 4 a newly molted female was observed attached 3 mm. to one side of its nymphal skin.

In the case of a cow infested November 19, an unattached newly molted female was observed December 19. She was in the hair just above a male which was attached beneath a nymphal skin. On December 20 the female was found attached near the male.

### EARLY DISTINGUISHING OF FEMALE NYMPHS BY MALES.

Some interesting observations were made which show how early the male tick may distinguish a nymph as a female and locate beneath it. On November 19, 1907, a cow was infested with larvæ. November 28, three males belonging to a previous infestation were found on the right side of the dewlap, and on November 29 and December 2 two more were found, making five in all. On the latter date two of them were located beneath nymphs, and on December 3 and 4 two more located themselves beneath nymphs. December 5 the first male nymphs of the new infestation molted. They were located on the posterior part of the body. December 6 the male of the previous infestation that had not sought a nymph had disappeared and a male was found beneath a nymph on the opposite side of the dewlap. This was very likely the male of the previous infestation which had disappeared from its former location, as none of the nymphs of the new infestation had molted on this region of the body. The nymphs selected by the five males molted from December 9 to 16 and proved to be females. As observed in this case, therefore, female nymphs were sought out by males 13 to 17 days after the former had been placed on a cow as larvæ, and 3 to 7 days or more before they molted the second time.

### EXPERIMENTS IN TRANSFERRING TICKS ON CATTLE.

The following experiments were undertaken for the purpose of determining whether ticks which have accidentally dropped to the ground after molting or have been dislodged in some manner will reattach and develop, provided they reach a host. Ransom [17] (1906) showed that ticks removed shortly after the first and second molt, or just previous to the second molt, and permitted to molt in the laboratory will reattach themselves. Hunter and Hooker[12] (1907), after repeated attempts, succeeded in getting two ticks to reattach One was a female one-half engorged and the other an adult which molted in the laboratory. The former remained attached six days and then released its hold, although not fully engorged. It deposited several hundred eggs, which failed to hatch. The failure to hatch was not attributed to the reattachment of the tick.

*Experiment No. 1.*—December 7, 1907, a female recently molted was removed and placed on the dewlap. December 8, female had taken hold. December 13, female was still present. No further record.

*Experiment No. 2.*—December 8, a recently molted female was removed and placed on the outside of the left ear. December 9, tick had disappeared.

*Experiment No. 3.*—December 9, a female was removed and placed on the median line between the shoulders. December 10, female had taken hold. A male was placed with it. December 11, male had disappeared. December 13, a male had located beneath the female. December 14, male had disappeared. December 17, female was shriveled.

*Experiment No. 4.*—December 14, removed a female one-sixth grown and placed it on the median line between the shoulders. December 15, female had disappeared.

*Experiment No. 5.*—January 22, 1908, removed four females recently molted and placed them on the escutcheon of a cow free from ticks. January 23, two of the ticks had attached themselves. The others had disappeared. January 25, one tick had disappeared. February 14, the remaining tick dropped from host, but died without depositing eggs.

*Experiment No. 6.*—January 24, transferred two young females to a new host. January 25, ticks had disappeared.

*Experiment No. 7.*—January 27, transferred three females just molted to a cow. They were removed as nymphs January 25 and molted January 27. They were placed on the escutcheon and in about half an hour had apparently attached themselves. January 28, ticks had disappeared.

*Experiment No. 8.*—January 30, placed a female just molted on a cow. Female was removed as a nymph January 25 and kept in the laboratory. Molted January 30. January 31, tick still present. February 2, tick had disappeared.

*Experiment No. 9.*—February 23, placed a female, which molted in the laboratory February 22, on the escutcheon of a tick-free cow. February 24, female had disappeared.

*Experiment No. 10.*—February 26, placed two females, which molted in the laboratory February 24 and 25, on the escutcheon of a cow. At the end of 30 minutes they had apparently attached themselves. February 27, ticks had disappeared.

*Experiment No. 11.*—March 2, a female which was removed February 24 and molted in the laboratory March 1 was placed on a cow. At the end of three hours it was observed attached to the udder. March 4, tick had disappeared.

*Experiment No. 12.*—March 5, placed two females on the dewlap of a cow. They were removed as nymphs on February 24 and March 2 and molted in the laboratory March 5. March 6, ticks had disappeared.

*Experiment No. 13.*—March 7, placed two females on the escutcheon of a cow. They had been removed as nymphs March 2 and 4 and molted March 7. March 8, ticks had disappeared.

*Experiment No. 14.*—March 9, placed a female, which was removed as a nymph March 2 and molted March 8, on the left shoulder of a cow. March 10, tick had disappeared.

*Experiment No. 15.*—March 18, placed three females on the flank of a cow. They had been removed as nymphs March 17 and molted March 18. They had disappeared half an hour later, apparently having been licked off.

*Experiment No. 16.*—March 19, three females, collected as nymphs March 17 and molted March 19, were placed on the neck of a cow. March 20, one tick was attached to the shoulder, one to the dewlap, and the other had disappeared. March 21, the tick on the shoulder had disappeared. March 29, tick was about one-third engorged. April 1, tick was dead.

*Experiment No. 17.*—March 26, placed a female, which was collected as a nymph March 17 and molted March 26, on the neck of a cow. The tick disappeared the same day.

*Experiment No. 18.*—April 1, two females, which were collected as nymphs March 17 and molted March 31 and April 1, were placed on the neck of a cow. April 2, ticks had disappeared.

*Experiment No. 19.*—April 2, placed a female, which was collected as a nymph from a horse and molted April 2, on neck of a cow. April 4, tick was present. April 5, tick had disappeared.

In the above experiments 32 ticks, shortly after the second molt, were applied with special care. Twenty-four of them disappeared either on the same or the following day and 8 remained attached for periods ranging from 2 to 23 days. The one that was attached for 23 days (Experiment No. 5) became nearly engorged and dropped, but failed to deposit eggs. None of the remainder approached engorgement. Two of them died attached to the host, while the rest simply dropped off.

Unfortunately no tests were made with ticks in the stage just after the first molt. It seems likely that ticks in this stage, on account of their smaller size, would attach themselves with much greater facility and develop to maturity more frequently than do adult females. A female one-sixth grown, mentioned in Experiment No. 4, failed to attach.

In addition to this test, on April 13, 1908, five females, which had just been collected from a horse, ranging in size from just after the second molt to one-sixth grown, were placed on a cow, but none of them became attached.

## EXPERIMENTS ON REARING UNFERTILIZED FEMALES.

It is next to impossible to arrange an experiment for rearing unfertilized females that entirely excludes the possibility of error. Perhaps the most reliable method would be to obtain an animal free of all ticks and infest it with females that have molted in the laboratory. Unfortunately all the experiments described in the preceding section to rear females to engorgement by this method were unsuccessful except in the case of one female transferred to a new host shortly after molting (see Experiment No. 5, p. 28), which, however, failed to deposit eggs. In some additional work attempted along this line a different method was used. An animal free of ticks was infested with a small number of larvæ. The male nymphs were removed as soon as the sexes could be distinguished. The animal was examined twice a day, but in spite of the greatest care some males escaped and were occasionally found beneath females. In such cases both were removed and destroyed. The females kept under observation were examined as a rule both morning and evening. It can not definitely be asserted that they were unfertilized, since the method used did not exclude this possibility, but at no time were males found beneath them. The results, while they prove nothing with regard to undoubtedly unfertilized females, show at least two interesting things which will be mentioned below.

April 19, 1908, a cow was infested with larvæ. About one hundred were placed on the right side of the neck and the same number on the inside of the left thigh. All the nymphs that, so far as could be judged, were males were removed as soon as possible. On May 12 a female with a male beneath her was removed. Both were destroyed. May 22 a female dropped. It was not as large as an ordinary engorged female. Length 8 mm., width 5 mm., very thin in the dorso-ventral axis, color yellow. This tick began to oviposit May 27. The eggs developed white spots but failed to hatch. On May 24 one female dropped but could not be found. On May 26 another female dropped and was lost. No more ticks were collected from this animal.

A cow was infested May 27. Larvæ were placed on the escutcheon and right side of neck. Male nymphs were removed as soon as possible but some males escaped.

June 20, removed a fully engorged female beneath which a male was never seen. Oviposition began June 24. Eggs hatched.

June 22, removed a fully engorged female beneath which a male was never seen. Oviposition began June 24. Eggs hatched.

June 26, a fully engorged female dropped. A male was never observed with it. Oviposition began June 29 and eggs hatched.

June 26-27, night, a female nearly engorged dropped. A male was never noticed with her. Oviposition began June 29 and the eggs hatched.

June 29, removed two females nearly engorged; males were never seen with them. Both oviposited and though the white urinary vesicle appeared in the eggs not more than half a dozen hatched.

July 18, removed a female two-thirds engorged. Eggs did not hatch.

July 24, removed the last two females. They were not fully engorged and had grown very slowly. One died without ovipositing and the other laid a normal number of eggs but these failed to hatch.

From the above observations it can be concluded that females which at least have not had males with them for any length of time (and possibly not at all) will as a rule deposit a normal number of viable eggs. It should be mentioned that Morgan[13] (1899, p. 129) records observations on a presumably unfertilized female which laid viable eggs. Another thing indicated is that the parasitic period may be prolonged by excluding males, and in consequence of this the period that an animal remains infested is increased. In the case of the animal infested May 27, the duration of the infestation was 58 days or about one and a half times as long as occurred in the case of a cow infested May 23 of the same year. That the adult period is not always prolonged, however, is indicated by the experiment with a newly molted female that was transferred to an animal January 22 and dropped February 14, after an adult period of 23 days (Experiment No. 5, p. 28). This comes within the range (8 to 33 days) of the adult period obtained at about the same time on another animal (Table 2, Appendix). The tick obtained from the cow infested April 19 remained on the cow 33 days and the one that dropped May 26, 37 days, which is 5 days and 1 day less, respectively, than the duration of an infestation of another animal made April 4.

### THE OCCURRENCE OF DEAD TICKS ON CATTLE.

Dead ticks are frequently found attached to cattle. In some instances, especially in the case of partially or fully engorged females, they have clearly been crushed by the host rubbing or coming in contact with fences, buildings, etc. In many instances, however, dead ticks are found that have not been injured in this manner, and a microscopical examination of a number of such ticks failed to reveal a fungus or anything that might have caused death.

In observations made from November 6, 1907, to March 26, 1908, on animals used in the life-history studies, dead nymphs were noticed most frequently, females next, and only one male and one larva were found dead. The dead ticks did not occur uniformly over the entire body. The greater number were found on the neck and shoulders, and then in the order named, on the tail, dewlap, vulva, and flank.

The following is a record of dead ticks found on cattle:

November 6, 1907, one nymph on tail. November 10, one nymph on tail. December 6, one nymph on side of neck. December 14, one nymph on side of neck. December 30, one nymph on dewlap. February 1, 1908, one nymph near vulva. February 14, one nymph on neck. February 20, female one-sixth grown, on shoulder. February 21, three nymphs on neck. February 22, one female on neck. February 23, two nymphs on neck. February 26, female, nearly grown, at root of tail. February 27, two nymphs on neck. March 5, one larva on shoulder. March 17, one nymph on neck. March 19, one nymph on shoulder. March 19, one male on neck. March 24, one nymph on dewlap. March 25, a female attached near the edge of a pustule on the right flank. March 26, female about one-third down on tail. She had a male beneath her.

### HOST RELATIONS OF THE CATTLE TICK.

*Ixodes annulatus* (= *M. annulatus*) was first reported by Say (1821) from a deer (*Cervus virginianus*–*Cariacus americanus*) from east Florida. There are specimens in the collection of the zoological laboratory of this bureau collected from a deer in Santa Barbara County, Cal., and at San Simeon, San Luis Obispo County, Cal. Besides cattle, this tick occurs frequently on horses and mules running on infested pastures. Hunter[11] (1907) reports the tick on sheep (*Ovis aries*) in Jackson, Calhoun, and Victoria Counties, Tex. During the summer and fall of 1907, in the course of the work upon which the present paper is based the cattle tick was collected from sheep at the Alabama Experiment Station, Auburn, and also in Wilcox County, Ala. There are specimens in the zoological laboratory of this bureau from a goat (*Capra hircus*) collected in Elmore County, Ala.

Ransom [17] (1906) in an account of an experimental infestation of a cat reports ticks present in the larval and nymphal stage. Only one nymph molted—a female that never became engorged. Males and females that molted in the laboratory attached themselves to a tame rabbit, but the females failed to develop further. Dinwiddie [9] (1908) reared experimentally the cattle tick on a dog. The females failed to reach the usual size but deposited viable eggs.

In the course of the investigations reported in the present paper larvæ were applied to the rabbit, cat, dog, and sheep.

### INFESTATION EXPERIMENTS ON RABBITS.

*Experiment No. 1.*—A white rabbit was infested July 25, 1907, with larvæ hatched June 28–July 13. July 26, one larva attached to ear; four or five found crawling about through the hair. July 27, five larvæ found attached to body and ears. July 30, one of the larvæ found on ear continues to develop; one on the body dead, having developed very little. August 1, one larva in the act of molting. August 6, a nymph found on ear. August 12, nymph on ear still present, but not developing. A male nymph had molted. August 17, no ticks could be found.

*Experiment No. 2.*—August 19, 1907, white rabbit infested with larvæ hatched June 28–July 13. August 20, many larvæ found attached to the ears. August 26, one larva found on tip of right ear. August 29, one nymph found on inside of the tip of the right ear. September 4, nymph still present. September 9 and 16, no ticks could be found.

*Experiment No. 3.*—September 25, 1907, white rabbit infested with larvæ, the progeny of ticks collected August 16 from a horse. October 8, no ticks could be found.

*Experiment No. 4.*—December 12, 1907, placed two females recently molted on a white rabbit. The rabbit was also infested with larvæ. December 13, no ticks present. December 14, placed two more females recently molted on the rabbit. December 15, the two transplanted females have disappeared. December 19, 30, and January 17, 1908, no ticks present.

*Experiment No. 5.*—January 20, 1908, a black and white rabbit infested with larvæ. Examinations made January 22, 30, and February 11 revealed no ticks.

*Experiment No. 6.*—March 2, 1908, a black and white rabbit infested with larvæ. March 4, three dead larvæ on the ears—two attached and one in the hair. Two live larvæ seen crawling over the hair of the head and face. March 13, two dead larvæ noted. Neither showed any development. March 27, no ticks present.

*Experiment No. 7.*—June 18, 1908, white rabbit infested with larvæ. July 2, four nymphs and a female just molted located on the ears. July 6, female had disappeared. All the nymphs were dead.

*Experiment No. 8.*—June 18, 1908, a white and gray rabbit was infested with larvæ. July 11, three dead nymphs were found on ears, one in stage of molting. A nymphal skin was attached to the right ear, but the tick that had issued from it could not be found.

It is evident from the above experiments that the rabbit is not an appropriate host for the cattle tick. Out of a large number of larvæ placed on each rabbit none in some cases, in others comparatively few, attached themselves. It also appears that adults either resulting from nymphs dislodged from cattle, or themselves dislodged from cattle, would not be likely to attach to a rabbit in case an opportunity were presented.

Larvæ, nymphs, and adults (males and females) were reared on rabbits, but in no case did females develop beyond the second molt. The blood of the rabbit, or something else peculiar to the animal, is unfavorable to the tick. This is evidenced by the fact that many of the larvæ and nymphs die without reaching the point of molting. It seems possible, however, that in rare cases females might attain partial or complete engorgement on rabbits, but the chances against the tick on the rabbit are so great that such a possibility seems negligible for all practical purposes.

In the above experiments only tame rabbits were used. An attempt was made to raise a wild rabbit in captivity for use in the experiments, but this was unsuccessful. A number of wild rabbits obtained in the vicinity of Auburn, Ala., and in Wilcox County, Ala., were examined for cattle ticks with negative results.[a] Farmers and stockmen in the South frequently state that they have found cattle ticks on wild rabbits, but observation and experiment tend to show that these must be other species of ticks, probably most commonly *Hæmaphysalis leporis-palustris*.

### INFESTATION EXPERIMENTS ON A CAT.

*Experiment No. 9.*—July 24, 1907, a kitten was infested with larvæ hatched June 28–July 13. July 25, one larva was found attached to the inside of thigh. July 26, larva on thigh still present and another located on left ear. July 29, larvæ still present. July 31, larva on thigh molted. August 6, nymph still present. August 10, nymph disappeared. August 17, no ticks found.

*Experiment No. 10.*—August 19, kitten infested with larvæ hatched June 28–July 13. August 20, a few larvæ attached to the ears and abdomen. Examinations on August 26, 30, and September 4 revealed no ticks.

*Experiment No. 11.*—A third infestation of the kitten was made December 12 without result.

It appears so far as the above experiments go that the cat is even a less favorable host than the rabbit.

### INFESTATION EXPERIMENT ON A DOG.

*Experiment No. 12.*—A dog was infested August 30, 1907, without result.

### INFESTATION EXPERIMENTS ON SHEEP.

Seven attempts were made at various times to infest sheep with the tick, and six of these were unsuccessful. In the case of one of the unsuccessful attempts, made May 15, 1908, the animal was shorn on the previous day to allow the larvæ to reach the skin with greater ease. In another, made September 25, the progeny of females matured on a horse were used.

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[a] In July, 1910, 20 cottontails and 6 jack rabbits were shot on the Rincon Ranch, Gregory, Tex., and examined for cattle ticks, with negative results. The rabbit tick (*Hæmaphysalis leporis-palustris*) was found on both jacks and cottontails, but was much more abundant on the former.

The record of the one infestation that was partially successful is as follows:

July 24, 1907, a sheep was infested with larvæ hatched June 28–July 13. July 27, several larvæ were attached to the ventral surface of the body. August 10, one female tick a little over one-fourth grown was located on the outside of the left ear. August 12, tick had disappeared. There was a bloodstain where the tick had been attached, suggesting that it may have been crushed.

In two of the negative experiments dead larvæ were found in the wool and also attached to the skin. At each infestation thousands of larvæ were applied, and, in most cases, to all parts of the body. The very small number of larvæ that attached themselves indicates that sheep are not favorable hosts for the tick. The presence of dead larvæ seems to indicate that there are conditions on the surface of the body or substances in the skin and blood unfavorable to the tick.

### THE NATURAL OCCURRENCE OF THE CATTLE TICK ON SHEEP.

In order to determine to what extent, under natural conditions, sheep serve as hosts for the cattle tick, some field experiments were carried out, and in addition to this a considerable number of sheep running on infested pastures were inspected.

In one of the field experiments six native sheep were allowed to run with two cattle on an infested pasture containing about 4 acres, from July 18, 1907, to November 6 of the same year. No ticks were found at any time on the sheep, although the two cattle carried a moderate infestation until shortly before the close of the experiment, when the weather had become cool.

In a second experiment six native sheep were allowed to run alone on an infested pasture similar to the above from July 18 to November 26, 1907. A ram and ewe were carefully examined on September 7. The ewe was free of ticks and the ram had six ticks, as follows: One engorged female, two males, and a dead female shortly after the second molt, on the neck, one female about one-eighth grown on the outside of the upper portion of one fore leg, and another female one-sixth grown on the abdomen where hair was present. The engorged female was unattached, but entangled in the wool in such a manner that it could not drop from the host. It had been in this condition for several days, as it had begun to oviposit. All of the sheep were examined with great care on November 26, when the experiment was closed, and were found free of ticks.

Through the kindness of Prof. D. T. Gray it was possible to inspect sheep for cattle ticks at the experiment station at Auburn. The sheep were running on an infested pasture, mostly woodland, along with a few cattle.

On September 26, 1907, five sheep were subjected to a hand inspection and two were found infested. A native ewe had a female tick on its ear; and a Dorset ram carried a number of males, females, and one nymph. Some of the males were dead. They were unattached and located in the wool. One female just after the second molt had a male beneath her. The largest female collected was possibly a little more than one-sixth grown. Most of the ticks were located on hairy parts of the body, especially the legs. On one native ewe two dead larvæ were found.

On October 3, 12 native ewes and the Dorset ram in the above flock were inspected. The ewes were free (one harbored a dead larva) and the Dorset ram harbored two males. The skin of 7 of the ewes was oily, that of the other 5 was moderately oily, and that of the Dorset ram was not oily. On October 12 the ram was inspected again. The wool and skin were very free from oil. Ticks were found as follows: Two females one-third and one-sixth grown with males beneath them on one hind leg a short distance above the hoof; a female just after the second molt on the posterior surface of the thigh with a male situated some little distance below it; a female one-fourth grown with a male, located on the scrotum; and a dead male in the wool. On October 14 one of the females on the leg and the one on the scrotum had become nearly engorged and were removed. The former was crushed in removing. On October 16 another female nearly engorged was removed from the hind leg. Both of the uninjured ticks laid viable eggs.

On November 12 to 13, 1907, 36 sheep, principally grade Southdowns, in Wilcox County, Ala., were subjected to a careful hand inspection. These sheep had been running continuously during the summer and fall with 240 head of cattle that were grossly infested with ticks prior to October 24, when they had been dipped. All the sheep were in high flesh. All but one of them were free from ticks. Thirteen of the sheep had wool that was not oily; 14 had moderately oily wool; and 8 had oily wool. The one infested, a ram with moderately oily wool, had a female tick one-half grown on the hairy portion of the scrotum.

On November 14 to 18 a flock of 125 sheep in the same locality was inspected. They had been running continuously during the summer and fall in a pasture of several hundred acres with over 200 cattle which, at the time of the inspection, were grossly infested with ticks. Three sheep, or about 2 per cent of the entire flock, were found infested with live ticks. Dead ticks alone were found on 31 sheep, or 25 per cent of the flock. Rams were the hosts for the live ticks in all three cases, and in the case of two of them the ticks were attached to the scrotum. One ram had two ticks, a female just after the second molt and another one-third engorged; another had but one tick, a female, newly molted, and the remaining one had a half-grown female on the hairy portion of the leg. The wool of the first was moderately oily and that of the other two not oily.

Dead ticks were found on 32 sheep. This includes one that also had live ticks. Ticks in the larval stage were found on all these sheep, and in addition one dead male was present in each of four instances. The larvæ were attached to the skin of the woolly regions of the body. When they were removed a small scale of epidermis of the host was brought way with the mouth parts, indicating that the larvæ had actually taken hold. The males were found unattached in the wool. The condition of the wool of the entire flock was noted for the purpose of determining, if possible, whether the amount of oil on the wool plays any part in preventing ticks attaching to sheep. Eighty-six sheep, or 69 per cent, had wool not oily; 38 sheep, or 30 per cent, had wool moderately oily; and 1 sheep, or about 1 per cent, had oily wool. Twenty-seven per cent of the first class, 29 per cent of the second class, and zero per cent of the third class of sheep carried ticks either dead or alive. From this it would appear that the relative amount of oil on the wool bears no important relation to the presence of ticks.

Summarizing the results of the observations on the natural infestation of sheep, it may be said that live ticks were found on the ears, neck, legs, abdomen, and scrotum. In no case were they present in great numbers. Rams seem to be much more favorable hosts than ewes. Taking into account all the inspections made, ticks were found on rams eight times and on ewes twice. In view of the large number of ewes inspected as compared with the rams this result can not be considered accidental.

### THE PROGENY OF FEMALES MATURED ON SHEEP NONINFECTIOUS.

As previously stated, two of the female ticks that matured on sheep laid viable eggs. One collected October 16, 1907, began to lay October 23, 1907; hatching began April 9 and ended April 17, 1908. The other, collected October 14, 1907, began to lay October 22 and hatching began April 11, 1908.

On May 2, 1908, the larvæ from the above ticks were placed on a northern cow (No. 603) about 10 years old, at the Bureau of Animal Industry Experiment Station, Bethesda, Md. Six hundred and forty-three females matured, but the cow continued well and in good condition, the temperature and number of erythrocytes remaining normal.

On July 15, 1908, the progeny of ticks collected from the above cow, May 28, 1908, were placed on two northern cattle, a bull (No. 585) and a heifer (No. 591), each about 1 year old. The temperature of both animals remained normal.

On September 14, 1908, and a number of times thereafter three northern heifers (Nos. 582, 583, 584), each about 1½ years old, were infested with the progeny of ticks collected from bull No. 585, August 8, 1908, but none of them developed fever.

The above experiments show that the larvæ were noninfectious, but it is not known, of course, whether the two females of which they were the progeny belonged to an infectious brood, and furthermore, if this were the case, it could not be known whether the two females were infectious or not in their larval state, since it is fair to assume that only a certain per cent of the progeny of infectious ticks are infectious. Since, however, the particular sheep from which they were collected ran on a pasture where infectious ticks undoubtedly occurred and since ticks had been observed on this sheep a number of times, the chances are, if the Texas-fever parasite could survive in the blood of sheep, the blood of this one would have been infectious and at least some of the progeny of the two females would have proved infectious.

## MAN AS A HOST OF THE TICK.

So far as known the cattle tick in its larval stage does not attack man. Persons handling these larvæ in the laboratory and passing through fields infested with only cattle ticks are not attacked. Ransom[17] (1906) reports two experimental and one accidental attachment of adults that molted in the laboratory. Below are records of the attachment of ticks to man, obtained in the course of the present investigations.

On June 18, 1907, 11.30 a. m., a female specimen of *Margaropus annulatus* about one-third engorged was placed on the calf of the leg. Shortly after noon it attached itself. It was removed June 19, 2.45 p. m., having drawn blood for more than 24 hours. At this time it had attained two-thirds of the usual size of an engorged tick. The place where it was attached became highly inflamed, acquiring a purplish color.

On August 13, 1907, a female that had molted in the laboratory on August 7 was placed on the thigh. The tick attached itself, but thereafter changed its location many times. It was present for several days and then disappeared.

On August 27 a nymph, shortly after the first molt, was placed on the arm. It attached itself and remained so for several hours and then disappeared, probably having been dislodged by the clothing.

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# APPENDIX.

**TABLE 1.**—*Individual records of ticks used in experiments.*

| Number of tick. | Date collected. | Number of eggs deposited. | Preoviposition period. | Oviposition period. | Incubation period. | Hatching period. | Minimum longevity. | Maximum longevity. | Entire time. | Per cent hatched. |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1907 | | *Days.* | *Days.* | *Days.* | *Days.* | *Days.* | *Days.* | *Days.* | |
| 1 | June 1 | 630 | 7 | 4 | 24 to 32 | 7 | 13 | 50 | 83 | 86 |
| 2 | do | 2,276 | 7 | 10 | 24 to 31 | 11 | 9 | 46 | 79 | 94 |
| 3 | do | 877 | 7 | 5 | 24 to 32 | 7 | 5 | 52 | 85 | 93 |
| 4 | do | 3,095 | 6 | 13 | 23 to 31 | 12 | 4 | 48 | 83 | 91 |
| 5 | do | 1,036 | 7 | 3 | 25 to 34 | 11 | 15 | 54 | 88 | 93 |
| 6 [a] | do | 2,150 | 9 | 9 | 23 to 31 | 10 | 7 | 65 | 100 | 73 |
| 7 [a] | do | 2,614 | 6 | 14 | 22 to 33 | 10 | 3 | 55 | 90 | 95 |
| 8 | July 1 | 3,000 | 4 | 17 | 20 to 25 | 11 | 22 | 82 | 112 | 96 |
| 9 | do | 3,562 | 4 | 18 | 20 to 25 | 17 | 16 | 62 | 91 | 96 |
| 10 | do | 1,863 | 4 | 5 | 20 to 27 | 9 | 20 | 85 | 112 | 97 |
| 11 | do | 3,515 | 4 | 20 | 19 to 25 | 15 | 16 | 75 | 103 | 95 |
| 12 | do | 1,858 | 4 | 4 | 20 to 25 | 4 | 24 | 55 | 82 | 90 |
| 13 [a] | do | 3,820 | 4 | 16 | 19 to 25 | 15 | 20 | 67 | 98 | 94 |
| 14 [a] | do | 2,814 | 3 | 10 | 20 to 25 | 9 | 19 | 79 | 109 | 96 |
| 15 | Aug. 1 | 3,683 | 3 | 15 | 20 to 25 | 8 | 22 | 160 | 187 | 90 |
| 16 | do | 2,972 | 3 | 18 | 20 to 24 | 15 | 10 | 187 | 218 | 96 |
| 17 | do | 2,536 | 3 | 15 | 20 to 25 | 15 | 4 | 152 | 180 | 97 |
| 18 | do | 2,820 | 3 | 17 | 19 to 25 | 16 | 9 | 170 | 198 | 98 |
| 19 | do | 2,700 | 3 | 12 | 20 to 27 | 14 | 11 | 192 | 221 | 97 |
| 20 [a] | do | 1,851 | 3 | 13 | 20 to 25 | 12 | 6 | 144 | 172 | 98 |
| 21 [a] | do | 2,267 | 3 | 19 | 21 to 26 | 14 | 9 | 192 | 221 | 94 |
| 22 | Aug. 31 | 2,809 | 3 | 19 | 28 to 54 | 39 | 5 | 224 | 258 | 83 |
| 23 | do | 2,699 | 3 | 18 | 29 to 48 | 31 | 13 | 204 | 240 | 95 |
| 24 | do | 2,049 | 4 | 15 | 30 to 50 | 31 | 7 | 196 | 234 | 66 |
| 25 | do | 2,266 | 3 | 19 | 30 to 66 | 49 | 11 | 219 | 270 | 57 |
| 26 | do | 2,262 | 4 | 14 | 29 to 52 | 34 | 5 | 234 | 272 | 95 |
| 27 [a] | do | 39 | 4 | 2 | | (b) | | | | |
| 28 [a] | do | 2,344 | 2 | 14 | 29 to 50 | 32 | 7 | 192 | 230 | 97 |
| 34 | Oct. 1 | 2,780 | 4 | 36 | 167 to 182 | 21 | 5 | 91 | 276 | 90 |
| 35 | do | 2,942 | 4 | 34 | 170 to 185 | 26 | 8 | 85 | 276 | 87 |
| 36 | do | 2,838 | 4 | 36 | 166 to 186 | 31 | 5 | 94 | 276 | 92 |
| 37 | do | 2,570 | 4 | 37 | 169 to 186 | 25 | 4 | 92 | 281 | 77 |
| 38 | do | 3,383 | 4 | 35 | 170 to 186 | 24 | 4 | 99 | 288 | 82 |
| 39 [a] | do | 960 | 6 | 21 | 173 to 188 | 16 | 3 | 98 | 281 | 80 |
| 40 [a] | do | 2,467 | 4 | 31 | 165 to 185 | 29 | 3 | 90 | 279 | 84 |
| 45 | Nov. 1 | 2,961 | 7 | 99 | 151 to 170 | 13 | 8 | 69 | 239 | 6 |
| 46 | do | 1,936 | 9 | 81 | 139 to 158 | 11 | 9 | 60 | 236 | 4 |
| 47 | do | 2,281 | 10 | 80 | 118 to 125 | 7 | 21 | 37 | 213 | .09 |
| 48 | do | 991 | 20 | 118 | 154 | 0 | 25 | 25 | 200 | .1 |
| 49 | do | 2,855 | 8 | 151 | 138 to 158 | 13 | 13 | 76 | 244 | 4 |
| 50 [a] | do | 1,985 | 9 | 82 | 117 to 168 | 15 | 21 | 78 | 253 | 3 |
| 51 [a] | do | 1,896 | 9 | 78 | 122 to 169 | 18 | 5 | 73 | 244 | 7 |
| 61 | Nov. 30 | (c) | | | | | | | | |
| 62 | do | 3,207 | 58 | 54 | 57 | 4 | 20 | 27 | 187 | 1 |
| 63 | do | 2,103 | 98 | 20 | 58 to 60 | 11 | 10 | 91 | 249 | 18 |
| 64 | do | 3,023 | 38 | 87 | 51 to 68 | 11 | 7 | 57 | 215 | 4 |
| 65 | do | 357 | 70 | 40 | | (b) | | | | |
| 72 | Dec. 29 | (c) | | | | | | | | |
| 73 | do | 3,180 | 63 | 18 | 56 to 66 | 14 | 13 | 46 | 181 | 1 |
| 74 | do | 4,272 | 39 | 63 | 48 to 80 | 25 | 7 | 73 | 207 | 35 |
| 75 | do | 1,970 | 46 | 37 | | (b) | | | | |
| 76 | 1908<br>Jan. 1 | 3,173 | 63 | 24 | 48 to 67 | 14 | 8 | 69 | 201 | 25 |
| 77 | 1907<br>Dec. 30 | (c) | | | | | | | | |
| 82 | 1908<br>Feb. 4 | 4,276 | 28 | 39 | 48 to 65 | 26 | 4 | 99 | 189 | 81 |
| 83 | Feb. 3 | 3,900 | 29 | 36 | 45 to 62 | 25 | 6 | 76 | 172 | 86 |

[a] Eggs were not counted. The unhatched eggs and the larvæ in each tube were counted after all the larvæ had died.

[b] Eggs failed to hatch.

[c] Did not oviposit.

TABLE 1.—*Individual records of ticks used in experiments*—Continued.

| Number of tick. | Date collected. | Number of eggs deposited. | Preoviposition period. | Oviposition period. | Incubation period. | Hatching period. | Minimum longevity. | Maximum longevity. | Entire time. | Per cent hatched. |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1908 | | *Days.* | *Days.* | *Days.* | *Days.* | *Days.* | *Days.* | *Days.* | |
| 84 | Feb. 4 | 806 | 36 | 22 | 53 to 63 | 14 | 6 | 77 | 177 | 39 |
| 85 | Jan. 30 | 3,620 | 35 | 33 | 49 to 63 | 26 | 7 | 86 | 186 | 65 |
| 87 | ...do | 3,725 | 34 | 43 | 48 to 64 | 26 | 2 | 81 | 176 | 72 |
| 88[a] | Jan. 29 | 3,269 | 37 | 36 | 48 to 65 | 25 | 7 | 59 | 156 | 34 |
| 89[a] | ...do | 3,718 | 37 | 41 | 47 to 65 | 18 | 21 | 64 | 156 | 14 |
| 95 | Feb. 27 | 2,302 | 10 | 24 | 47 to 64 | 18 | 4 | 94 | 162 | 62 |
| 98[a] | Feb. 28 | 2,925 | 8 | 36 | 45 to 62 | 27 | 2 | 80 | 143 | 96 |
| 105 | Mar. 26 | 4,559 | 5 | 34 | 36 to 53 | 13 | 7 | 90 | 149 | 77 |
| 106 | ...do | 2,680 | 6 | 24 | 43 to 53 | 12 | 7 | 98 | 155 | 78 |
| 107 | ...do | 2,731 | 8 | 14 | 43 to 52 | 15 | 12 | 101 | 161 | 66 |
| 108 | ...do | 3,024 | 5 | 17 | 44 to 53 | 12 | 11 | 101 | 159 | 89 |
| 109 | ...do | 4,035 | 6 | 23 | 39 to 53 | 14 | 6 | 97 | 155 | 95 |
| 110[b] | Mar. 29 | 3,712 | 4 | 35 | 37 to 52 | 14 | 13 | 92 | 146 | 92 |
| 111[b] | ...do | 3,405 | 5 | 27 | 38 to 51 | 16 | 5 | 89 | 144 | 92 |
| 112[b] | ...do | 3,622 | 4 | 26 | 39 to 51 | 14 | 5 | 88 | 144 | 97 |
| 113[b] | ...do | 3,796 | 4 | 25 | 37 to 51 | 15 | 10 | 103 | 156 | 93 |
| 125 | Apr. 29 | 4,244 | 4 | 22 | 24 to 36 | 18 | 5 | 113 | 152 | 96 |
| 126 | ...do | 3,966 | 6 | 19 | 26 to 34 | 12 | 6 | 89 | 128 | 83 |
| 127 | ...do | 3,929 | 6 | 25 | 24 to 33 | 18 | 4 | 118 | 156 | 98 |
| 128 | ...do | 4,385 | 4 | 24 | 25 to 36 | 16 | 9 | 116 | 156 | 96 |
| 129 | ...do | 5,105 | 6 | 24 | 24 to 33 | 18 | 7 | 116 | 154 | 84 |
| 130[b] | ...do | 3,942 | 6 | 23 | 24 to 33 | 17 | 9 | 105 | 145 | 98 |
| 131[b] | ...do | 3,949 | 7 | 19 | 23 to 33 | 13 | 10 | 93 | 133 | 98 |
| 132[b] | ...do | 4,035 | 6 | 27 | 24 to 33 | 17 | 6 | 128 | 173 | 96 |
| 133[b] | ...do | 3,246 | 7 | 21 | 24 to 32 | 18 | 10 | 79 | 122 | 93 |
| 134[a] | ...do | .......... | 6 | 24 | 23 to 33 | 22 | 5 | 92 | 131 | .......... |
| 135[a] | ...do | .......... | 5 | 22 | 25 to 34 | 19 | 11 | 96 | 138 | .......... |
| 136[a] | ...do | .......... | 6 | 21 | 24 to 33 | 16 | 6 | 91 | 131 | .......... |
| 137[a] | ...do | .......... | 6 | 26 | 25 to 34 | 17 | 19 | 94 | 131 | .......... |
| 138[c] | ...do | .......... | 7 | 22 | 24 to 32 | 20 | ........ | 108 | 149 | .......... |

[a] Eggs were placed in test tubes directly on moist sand. No water was added to the sand after the tube was made.

[b] Eggs were placed in test tubes provided with two cardboard disks. No water was added to the sand after the tube was made.

[c] Eggs were floated on water in test tubes.

TABLE 2.—*Data on parasitic development of the ticks on animals.*

| Date animals were infested. | Date first larva molted. | Date last larva molted. | Minimum length of larval period. | Date first male nymph molted. | Date last male nymph molted. | Date first female nymph molted. | Date last female nymph molted. | Length of nymphal period of females. | Date first engorged female dropped. | Date last engorged female dropped. | Length of adult period. | Duration of infestation. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1907. | 1907. | 1907. | *Days.* | 1907. | 1907. | 1907. | 1907. | *Days.* | 1907. | 1907. | *Days.* | *Days.* |
| July 18 | July 25 |  | 7 | July 31 | Aug. 4 | Aug. 3 | Aug. 7 | 9 to 13 | Aug. 10 | Aug. 17 | 7 to 10 | 30 |
| Aug. 17 | Aug. 24 |  | 7 | Sept. 1 | Sept. 5 | Sept. 3 | Sept. 10 | 10 to 17 | Sept. 8 | Sept. 20 | 5 to 10 | 34 |
| Oct. 4 | Oct. 11 |  | 7 | Oct. 19 |  | Oct. 20 | Nov. 10 | 9 to 30 | Oct. 27 | Nov. 26 | 7 to 16 | 53 |
| Nov. 19 | Nov. 26 | Nov. 28 | 7 | Dec. 5 |  | Dec. 7 | Dec. 27 | 11 to 31 | Dec. 15 | Jan. 6, 1908 | 8 to 10 | 48 |
| 1908. | 1908. | 1908. |  | 1908. | 1908. | 1908. | 1908. |  | 1908. | 1908. |  |  |
| Jan. 3 | Jan. 10 | Jan. 15 | 7 | Jan. 19 |  | Jan. 19 | Feb. 5 | 9 to 26 | Jan. 27 | Mar. 9 | 8 to 33 | 66 |
| Feb 1 | Feb. 8 |  | 7 | Feb. 17 |  | Feb. 19 | Mar. 5 | 11 to 26 | Feb. 27 | Mar. 17 | 9 to 12 | 45 |
| Feb. 29 | Mar. 5 | Mar. 14 | 5 | Mar. 14 | Mar. 18 | Mar. 16 | Mar. 30 | 11 to 25 | Mar. 23 | April 13 | 7 to 14 | 44 |
| Apr. 4 | Apr. 10 | Apr. 11 | 6 | Apr. 18 | Apr. 23 | Apr. 20 | Apr. 26 | 10 to 16 | Apr. 26 | May 12 | 6 to 16 | 38 |
| May 23 | May 28 | May 31 | 5 | June 2 | June 13 | June 8 | June 14 | 11 to 17 | June 14 | June 29 | 6 to 15 | 37 |